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Location analysis of the Iowa feed manufacturing industry: least-cost alternatives

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LOCATION ANALYSIS OF THE IOWA FEED MANUFACTURING INDUSTRY:

LEAST-COST ALTERNATIVES

by

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I. INTRODUCTION AND STUDY OBJECTIVES

Among economists, farmers and legislators alike there is both broad agreement and disagreement on matters pertaining to agriculture. But unanimity prevails upon the observation that American agriculture is in an era of dramatic change. Agricultural production is becoming more "commercial" -- a term implying larger size per productive unit, stronger linkage to nonagricultural sectors of the economy and more sensitive response to economic incentives. An attendant result is that fewer and fewer farms are needed to sustain ever-higher levels of production.

Although the total number of farms declined from 5.8 million in 1939 to 3.4 million in 1964, the number of larger farms ($10,000 or more gross sales) actually increased 250 percent while their production tripled [Nikolitch, 1965]. Moreover, it was noted that the value of 1959 marketings was 170 percent of 1939 marketings and that a higher percentage of products purchased from larger farms were purchased for further processing. However, as noted in another United States Department of Agriculture (USDA) study [Nikolitch, 1964, p. 10], the growing point in agriculture is the larger commercial family farm. Data do not support the contention that corporate farms are displacing family farms as the basic organization of farm production. While 1.5 to 2 million farms will probably remain in 1980, it has been predicted that 1.1 million of these farms could easily produce the nation's food in surplus quantity and without liquidation of the family farm structure [Heady and Tweeten, 1963, pp. 480-481].

Years ago agriculture was more easily defined -- farming was a synonym. Today the definitional boundaries are subject to greater uncertainty and the source of considerable disagreement. H. F. Breimyer has put forth the thesis that modern agriculture be so broadly defined as to embrace the distributive density of its product as a composite, or sequence, of three separate and distinct economies [Breimyer, 1962, p. 679]. The three are production of primary products from soil, the conversion of feedstuffs into livestock products and the marketing of products from farm to retail. The latter "economy of agriculture" is the primary focus of the present study. Crop and livestock products are to be assembled, transformed, stored and distributed; these activities are performed almost entirely by a nonfarm economy of agriculture. The activity subset performed by the feed industry is the procurement of agricultural and non-agricultural outputs, and the transformation and distribution of its output for use as inputs by livestock producers. The changing structure of farm production has impact on the agricultural marketing economy, including the feed industry, from both input and output points of approach. The marketing economy has become more than a transmission agent. It has become an active contributor to "value added" while isolating primary and secondary agricultural production more completely from the consumer.

The feed industry has been alert to ramifications of a changing agriculture. Industry people anticipate further changes and recognize a two-fold need of lowering per unit costs of production and distribution yet meeting farm purchaser demands more precisely than ever before [Butz, 1965, p. 46]. University personnel have recognized that the structure and direction of research and education may need to be reshaped if the commercial agriculture of the future is to be serviced [Heady and Ball, 1965, p. 11]. In 1956 an agricultural economist prominent in the feed industry suggested the need for '. . . a study of supply, demand, and transportation costs as they combine to influence broad industry, location, plant size . . .' [Brensike, 1956, p. 197].

The growth pattern of the American commercial mixed-feeds industry will be documented later. Rapid growth has been experienced since post-World War II. What are the problems of an industry undergoing rapid expansion? What changes in production-distribution patterns are implied by rapid expansion? The problems of a relatively static industry tend to be primarily short-run in nature. That is, decisions must be conditional upon certain fixed facilities and locations. Given the present location, what is the least-cost pattern for selling and distributing the product? Given the existing physical plant and major equipment, how can per unit production costs be cut? Capital expenditures taking place in such an industry will likely be "maintenance of capacity" in nature rather than net investment in the sense of expansion. Some expansion would be expected as a bonus accruing from improved technology.

Rapid industry growth introduces vast complexity. The successful entities of the industry must be concerned with long-run problems while at the same time no less concerned with short-run problems. Meanwhile the interactions of competing (and/or complementing) short- and long-run considerations should be analyzed. In an expanding industry both short-run and long-run problems (for example, cost) are to be resolved; given the expectation of continued expansion, long-run considerations should take precedence. An industry's problems are compounded further when, in addition to demand expansion, it is confronted by rapid changes in the industry to whom the product is sold. Both features are valid for the feed industry today. However, there are opportunities when changes in the buyer industry are accompanied by demand expansion.

There is more than one context for analyzing these problems. At the firm level procurement, production and distribution problems would be considered according to each individual firm's objective function. Typically profit maximization is assumed -- under certain conditions cost (per unit) minimization is the same as profit maximization. Another context is that of social welfare; the scope might be national, regional, state or local. An example: the Iowa Development Commission might be regarded as responsible for interpreting the state-level social welfare function and acting accordingly. It seems quite clear that a minimum cost size and location pattern of an Iowa industry is beneficial to the state's inhabitants. Savings in product cost can only be passed along if they exist. The public policy issue which evolves is to facilitate the accomplishment of social welfare objectives as a by-product of individual firms striving to fulfill their individual objectives; the suggested approach would be *a priori* acceptance of a competitive market system based on free enterprise and functioning by interfirm coordination and allocation of resources. Public policy issues can be examined in three time dimensions: present (or some other moment in time); past, present and prospective trends; and the anticipated ultimate state of development [Fletcher, 1963]. It has been suggested that at least three broad criteria underlie public policy: maximizing consumers' satisfaction, economic growth and development, and economic justice.

Many specific objectives are relevant to either the individual firm or the societal context. Exceedingly important among these is the efficiency criterion of producing a given level of output at minimum cost. The setting of the present study is within this efficiency criterion. The focus of data analysis is the commercial mixed-feeds industry in Iowa. An abstract objective of the present study is to develop and use analytical procedures of sufficient generality to permit application not only to the feed industry elsewhere but to other industries in Iowa and elsewhere.

A. Objectives of the Study

The abstract objective of procedural generalization was alluded to previously. The specific objectives of the present study relate to the analytical capabilities of the procedures developed.

Conversely, the procedures were developed to achieve certain specific research objectives. The specific objectives outlined in this section will pertain to the Iowa feed industry. However, many of these questions could be asked of a variety of industries in a variety of geographic delineations.

The problematical situation out of which the specific objectives emerge is to find the least-cost location and size pattern for feed-manufacturing plants in Iowa. The solution should take account of changing levels of demand, the changing levels of available technology and the commercialization trends of modern farming. Are the existing feed manufacturing plants economically efficient in size? Are their locations optimal? And should there be more or fewer of them? It is probable that many plant managers are unsure of how their cost levels compare with levels that could be attained. This uncertainty might apply to procurement, production, distributing and selling costs or to some combination of the four. What is the current level of demand and what is a reasonable expectation for the future? The demand problem is compounded when product form and quality subsets are considered. Brand loyalties and corrollary services per "typical ton of feed sold" can differ as modern farming becomes more commercialized. For example, it is well known that farmers with higher gross farm incomes are more price-conscious and demand more services [Kohls, 1962; and Herder, 1960].

If a new plant is to be built, what equipment should be installed and what should be its capacity in relation to current or projected demand? Quality control questions arise. To what extent would vertical integration allow reduction of over-all industry costs? Few of these questions have simple answers. This study will not answer them all. It will attempt to answer a few of them. In addition, the procedures and results of the present study may afford a basis for fruitful further study.

The specific objectives of the present study will be listed. They fall into primary and secondary objectives. The former are goals relating to concrete answers to problems faced by the Iowa feed industry today. The secondary goals are to develop data which will be useful information in itself, besides as a means to achieve the primary objectives. The primary objectives are:

i) to determine the relationship between processing costs and volume for single-shift operations;

ii) to determine the relationship between processing costs and volume for double-shift operations;

iii) to determine the relationship between distribution costs and the number of plants;

iv) to determine the relationship between processing costs and the number of plants; and

v) to determine the optimum number, size and location of feed manufacturing plants in Iowa.

The secondary objectives are:

i) to derive a manufacturing cost standard which could be used as an industry benchmark;

ii) to develop a road mileage transportation matrix relating a reference point in each county to each Iowa population center of 5,000 persons or more; and

iii) to analyze costs of transporting feeds in Iowa.

This study concerns mixed-feeds manufactured by business entities. These feeds are to be fed to livestock and poultry; the product form may be either supplement or complete feed. The scope of the present study is the analysis of costs to process, sell and distribute feeds to the county or "wholesale" level. That is, the county is considered a trade area and distribution to the trade area delimits the marketing focus of the present study. Problems of within-county or retail handling and distribution are not included in the objectives of this research effort.

B. Analytical Procedure

Five basic steps were taken to reach the least-cost solution to the problem of optimal number, size and location of feed manufacturing plants in Iowa. Each involved a number of substeps. The basic methodology of each step will be outlined presently.

The initial step was to define the spatial area. The state of Iowa was chosen. Specifically, each of the 99 counties was taken to be a node of feed demand to be supplied by the feed industry. The availability of recent census of agriculture data enabled development of feed demand estimates for each county.

Next, potential plant site locations were selected. The choice was based arbitrarily on population figures from the 1960 population census. Only major population centers, defined as 5,000 or more persons, were considered to be potential plant sites. Fifty-one such population centers were defined for Iowa.

Data development as input for the model comprised the third step. Five substeps accomplished the task of meeting model data requirements. First, feed estimates were derived for each county. The primary basis was livestock numbers reported in the 1964 Census of Agriculture. The initial estimates were disaggregated into supplement and complete feed tonnages on the basis of Iowa Department of Agriculture data and the supplement-to-total concentrates levels recommended in the Iowa Farm Planning Manual. Second, several economic-engineering study results were synthesized to estimate a per ton cost-to-volume relationship in feed manufacturing. Thereby the economies of scale cost pattern was ascertained. Multiplication of each average cost by volume yielded total cost observations in relation to tonnage. Regression analysis on these points indicated a linear fit with a positive intercept. Third, a road mileage transportation matrix was developed for the state. Air distances were measured from each potential location to each county reference point. The air mileages were converted to road mileages according to the angle relationship between each set of points. The result was a 51 x 99 matrix of road mileages. Fourth, costs of transporting feeds in Iowa were determined. Costs per mile in relation to length of haul were obtained for large trucks (about 18 tons load average). Data sources were a survey of Iowa Commerce Commission filings on private operator and contract carrier tariff charges plus an Iowa State University survey of truck costs incurred by Iowa feed manufacturers. Finally, selling costs per ton were related to distance.

The fourth basic step of the research procedure began with calculation of each transportation cost and adding the appropriate selling cost to each. Then the relationship between distribution costs (transportation plus selling costs) and number, size and location of plants could be established. The computational nature of this step will be detailed in the discussion of the model.

The final step entailed combining the total distribution cost function and the manufacturing cost function -- both with respect to plant numbers. The vertical summation of these two functions resulted in a combined cost function. When the minimum point on the combined cost function is found with respect to plant numbers, the solution is found. The solution consists of the number of plants, the size of each, the specific location of each plant and which plants should produce for and distribute to each county.

II. THE COMMERCIAL MIXED-FEEDS INDUSTRY

A. Historical Perspective

Today the feed industry ranks among the largest 15 manufacturing industries of the United States and is the largest industry serving the American farmer [Schoeff, 1961, p. 7]. By way of contrast, in the late 1800's ". . . flour mills in Minneapolis dumped wheat bran into the river because nobody wanted to buy it. Cottonseed meal was used as a fertilizer, if used at all. Most of the linseed meal was shipped to Europe. Soybeans were known only in the Orient. Large milk companies did not permit the feeding of gluten feed to dairy cows, and tankage was almost unknown" [Wherry, 1947, p. 1].

Growth of the commercial feed industry has been allied closely with protein nutrition and the introduction of new by-products. The crucial ingredient in these by-products usually has been protein. Perhaps the biggest step forward in knowledge of nutrition was the discovery that the kind (or quality) of protein in livestock feed made an important difference in feeding results [Wherry, 1947, p. 27]. Today the amino acid breakdown of protein is well known; out of about two dozen, ten amino acids are "essential" for monogastric animals.

A comprehensive analysis of nutritional progress and recent statistics can be perused by consulting a book sponsored by the feed industry [MFMA, 1961]. A complete descriptive chronology of feed industry growth and development is offered by Wherry.

As the feed industry assumed an important role, a regulatory framework became necessary to protect farmers and reputable manufacturers alike. Buyers need some protection inasmuch as they are not able to judge quality by visual inspection alone. Federal regulation has focused primarily on feeds shipped in interstate commerce (beginning in 1906). In 1938 certain labeling requirements for feeds were established [Schoeff, 1961, p. 12]. By 1920 most states had laws governing intrastate feed industry activities. The first feed law of the State of Iowa was passed in 1907 [Wherry, 1947, p. 49].

Current federal law is two-pronged in regulation: products which have traveled in interstate commerce must comply with the Secretary of Agriculture's regulations, and the Food, Drug and Cosmetic Act requires labeling and other specifications to be met [Jacobson, 1963, pp. 630-631]. In Iowa, the feed industry operates within the regulatory framework set forth by the Iowa Commercial Feed Law of 1964 [Iowa Department of Agriculture, 1966]. The law covers licensing, registration, labeling, inspection and penalties for noncompliance.

B. The Feed Industry up to 1950

Rapid growth was experienced from the turn of the century to the Great Depression; some decline in production occurred during the depression period [Ralph, 1953, pp. 14-15]. Stimulated by increased economic activity, technological and nutritional programs, the desire for (and incomes to afford) better-balanced diets, higher prices for livestock and livestock products, and relative shortages of many kinds of feeds, the feed industry grew very rapidly in the post-depression period [Askew and Brensike, 1953]. Between 1939 and 1947 (data are not available for 1948 through 1953), the number of feed manufacturing establishments doubled while the value of their shipments (in dollar value) increased more than five-fold [Census of Manufacturers, 1966]. Even in constant dollars the implication is clear that the industry grew rapidly both with respect to number of plants and size per plant.

In the same period the increase in total feed fed was much less than the value of shipments increase. Total concentrates fed to livestock increased only about 10 percent [Hodges, 1964, pp. 10-11]. During the period in question, the rate of feed industry growth greatly exceeded the growth of demand for total feed concentrates. It is apparent that the feed industry expanded not only with increased demand for total concentrates but also by supplying an increasing proportion of total feed volume demanded.

Logic would suggest at least three sources of demand expansion for the output of the feed industry: rising population, rising per capita incomes and an increasing proportion of total concentrates supplied. The relationship to population is direct. The deduction toward the third source has been outlined. The positive relationship between per capita income and level of feed demand has been substantiated by various statistical studies [Fox, 1958; Hassler, 1962; and Ahalt and Egbert, 1965]. A fourth possible source of demand expansion is better feeding practices at the farm level. This factor will likely be of increasing importance as the structure of modern farming advances in the direction of commercialization.

If not before, the pattern of increased demand for commercial mixed feeds was well established in the post-depression period up to 1950.

C. Recent Feed Industry Developments and Trends

Changes in the feed industry may reflect both demand and supply forces. On the one hand, demand for feed and related services reflect changes resulting from farm commercialization and increased consumer demand for livestock products. On the supply side, technological developments affect production and transportation costs and alternatives. Several forces simultaneously affect the feed industry and decisions must reflect the net of competing and complementing forces if a firm is to remain competitive through efficient operation. Low unit costs allow plant managers to retain flexibility and the ability to compete.

Significant developments in the area of animal nutrition have affected the feed industry directly. In addition to protein research, nutrition advances with antibiotics, vitamins and trace minerals have come about since 1950. Producers using these products realize more efficient gains if the feeds are properly formulated. Thus the feed manufacturer has become the source of not only physical services (processing and distribution) but technology advances and ration formulation as well. It follows that as more knowledge is available and as a higher percentage of farmers utilize this knowledge, an increasing proportion of total concentrates fed is of commercial mixed-feed industry source.

At one time farmers depended upon the mixed-feed industry only as a supply of protein supplement. As farms shifted from highly diversified production patterns to more specialized production, livestock feeders began to purchase complete feeds as well as supplements. Often the specialized feeder does not have a large enough supply of farm-grown grains. Also, labor costs may be reduced since switching to complete feeds facilitates bulk handling. These considerations are much more relevant for feed-deficit as compared to feed-surplus areas such as Iowa.

The USDA develops official estimates of total concentrates fed and the animal units in each year. An animal unit is defined in terms of the feed consumed by one producing milk cow in one year according to a 1940-1945 base period. Conversions for other periods and other livestock classes are made to standard animal units. Table 1 presents the 1950 to 1965 data on total concentrates fed and index of animal units (base period 1957-1959 = 100). These data suggest a general pattern of increasing demand for feed concentrates. Comparison of the relative rates of increase indicates that concentrates fed per animal unit increased over the time period being depicted. This observation is illustrated in Figure 1. Figure 1 is a graph of the two time series comprising Table 1. It is clear that one source of feed industry growth is the generally increasing demand for concentrates as livestock feed. It will be useful to examine industry tonnage production.

The Census of Manufacturers uses the Standard Industrial Classification (SIC) digital classification. SIC code 2042 refers to the prepared animal feeds industry. The postwar to 1947 dramatic increase in both number of feed manufacturing establishments and the

Table 1. Total concentrates fed and animal concentrate units index, 1950-1965, United States[a]

Year	Animal units index (Base: 1957-59 = 100)	Total concentrates fed (million tons)
1950	99	126.1
1951	99	128.6
1952	95	117.6
1953	94	119.9
1954	97	119.8
1955	100	125.6
1956	97	123.6
1957	97	132.1
1958	102	143.1
1959	101	147.9
1960	102	153.1
1961	103	155.2
1962	105	154.1
1963	105	153.3
1964	102	150.4
1965*	103	162.9

*Preliminary.

[a]Source: USDA Statistical Bulletin No. 337, 1963 and annual supplements.

value of their shipments was noted earlier. There was a slight decrease in the number of establishments to 2,292 in 1954; then small consecutive increases to 2,379 in 1958 and to 2,590 in 1963 were noted [Census of Manufacturers, 1966]. Meanwhile, the value of shipments for SIC 2042 continued to increase strongly. The corresponding 1947, 1954, 1958 and 1963 shipment values were 2.1, 3.0, 3.2 and 3.9 billion dollars respectively. The Census of Manufacturers reported that the total number of employees decreased slightly over the same period of time although the payroll nearly doubled. The employment data suggest a capital for labor factor substitution trend.

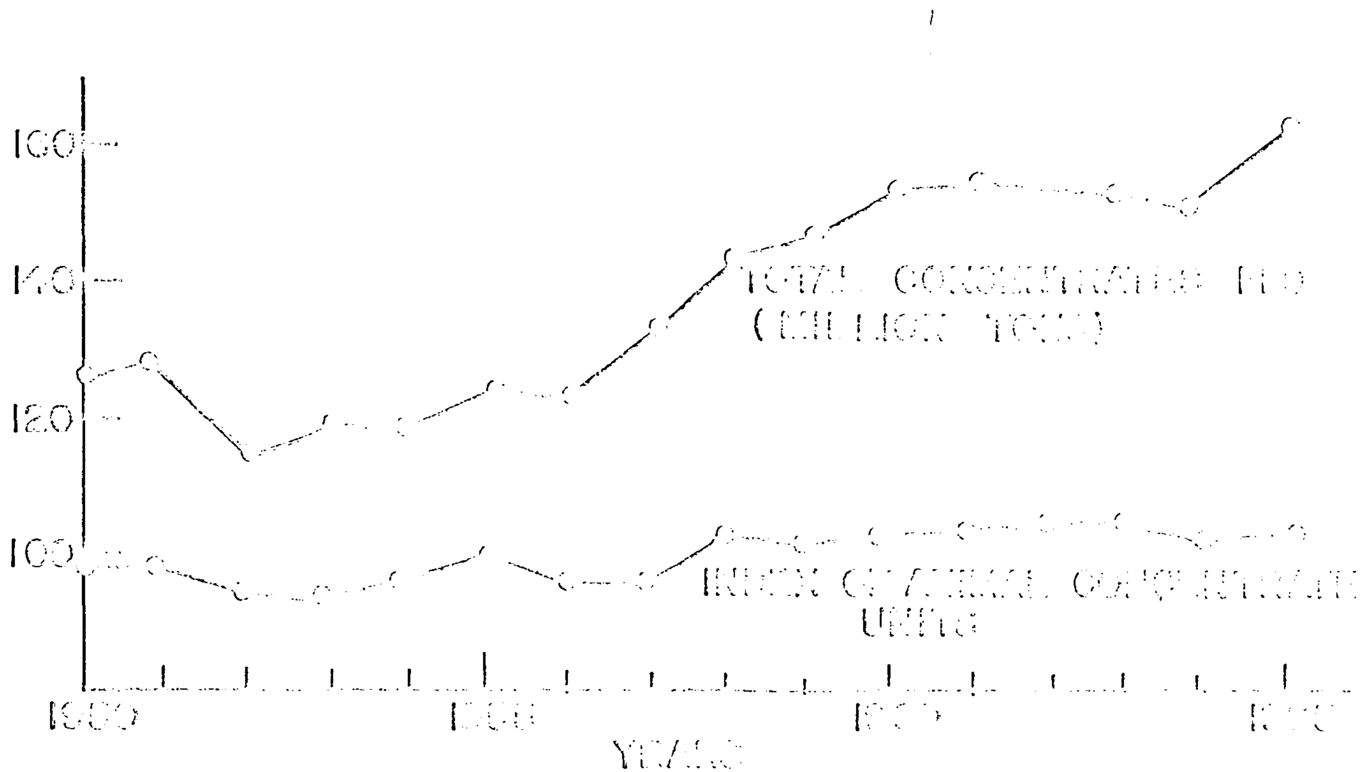

Figure 1. Index of animal concentrate units and total concentrates fed, United States, 1950-1965

The U.S. Department of Commerce has reported poultry and livestock feed production tonnages for each year beginning with 1961. The tonnages are presented in Table 2. These are U.S. tonnage totals for complete feeds, supplements and combined. Very little change is suggested for this short time period. It is to be noted that these estimates should be regarded as minimums since sampling coverage is incomplete. Not all estimates are available for the state level of disaggregation. However, complete feed and supplement tonnages are broken down regionally -- Iowa is one of seven states in the West North Central region.

Table 2. Feed production tonnages by manufacturing establishments, Current Industrial Reports, 1961-1964[a]

Year	U.S. total tonnage	U.S. complete tonnage	U.S. supplement tonnage	WNC complete	WNC supplement	Iowa complete
			(000 tons)			
1961	nd	42,664	nd	7,505	nd	2,028
1962	56,072	45,696	10,376	7,233	3,918	2,085
1963	57,347	47,006	10,341	7,273	3,960	2,294
1964	55,859	46,064	9,795	7,655	3,955	2,458

[a]Source: Current Industrial Reports, various issues.

The most recent Census of Agriculture was the first to obtain information on commercially mixed feeds, millfeeds and supplements purchased by farmers. The purchase reported for the U.S. amounted to 44.9 million tons while those in Iowa came to 2.6 million tons [Census of Agriculture, 1964]. The census reported that the average price per ton of commercial feed purchased in Iowa was $101.12; the corresponding U.S. figure was $83.22. Since the price per ton for supplements is much higher than that for complete feed, it is clear that the proportion of total feed which is supplement in form is much higher in Iowa than the national average. In fact, the Iowa price per ton exceeds any other state -- the closest is Illinois with $96.95 per ton.

However, the current Industrial Report for 1964 shows the Iowa average price per ton of complete feed to be $73.72 [Current Industrial Report, 1965]. All of these figures suggest two conclusions. The product form of much commercial mixed feed is supplement. Second, in Iowa the fraction of supplement to total tonnage is relatively high.

There are certain changes and trends which are important to the feed industry in Iowa. Other changes may affect regions not including Iowa. Still other trends are important only in a context of the national feed industry picture. An example of the latter is the trend to "Big John" bulk railroad cars; the resultant switch from truck to rail on long hauls has affected mainly feed-deficit regions. Vertical integration has become widespread in poultry production, especially broilers, and consequently has affected the feed industry in these production areas. Nearly all commercial poultry in the South is produced under some form of integrating arrangement. In 1964, 85 percent of all broilers were produced in the South Atlantic and South Central regions [Ray, 1965].

There are a number of trends which affect Iowa importantly. Most of these result from trends in livestock production. Farms are becoming larger, fewer in number, more specialized and more commercial in the sense of more sensitively responding to economic incentives. The farm production pattern change from diversification to specialization has meant more livestock produced at each production node but fewer nodes. In general, a capital for labor factor substitution has taken place as livestock production efficiency has improved. How should the needs of the larger farm producer be met? Competition often has forced direct selling -- and frequently bulk delivery to the feedlot. A corollary result has been a general trend toward more direct demand orientation of the industry. Yet the industry needs dealers. One feed company executive told his colleagues, "The large corporations won't crowd independent dealers out. Large feed manufacturers have had company-owned stores in the past, but they gradually got rid of them. They found that with a chain organization, with wage regulations and other problems, it was hard to make a go in competition with independent dealers" [Runke, 1965, p. 68].

The service center idea has taken hold in the feed industry. Of course, this is at the retail level. As farming has become more commercial, farmers have needed more service. They have need of a broader range of feed-related items such as animal health products. The busy livestock producer apparently prefers the "one-stop" approach to his purchases.

Another trend is to provide more credit and financing. As the farmer responds more sensitively to economic incentives, he will be deterred less by traditional aversion to debt. If anticipated risk-discounted returns exceed borrowing costs, it is sound business practice to finance the operation by borrowing. Moreover, nutritional and animal health advances have tended to reduce the risk in livestock production. Credit needs have expanded. Financing arrangements between feeder and feed supplier have become more frequent; a detailed analysis of such arrangements has been made using feed industry data [Phillips, 1962].

The demand for livestock products, from which feed demand is derived, is conditioned by consumer preferences. As consumption of a class of livestock product rises (lowers), so should its production rise (lower) -- the demand for that particular class of livestock feed will be affected. Between 1950 and 1965, the per capita livestock products consumption trends were as follows: beef and veal up 36 percent; pork down 15 percent; chicken meat up 62 percent; turkey up 80 percent; dairy products down 8 percent; eggs down 20 percent; and lamb and mutton down 8 percent [USDA Statistical Bulletin No. 364, 1963 and annual supplements]. The trend is distinctly upward for beef and poultry products while down for the other livestock products. Downward per capita trends do not necessarily suggest that aggregate demand falls. Examining the pork case, the per capita decrease in consumption has been about 1 percent per year since 1950; if population increases more than that rate aggregate demand for pork can actually increase.

Geographic location of livestock and poultry is of vital importance to feed firms. Certain shifts have taken place in recent years. Such shifts take on further relevance when occurring at the same time as feed industry decentralization trends. Recent geographic shifts in livestock and poultry have been examined by the American Feed Manufacturers Association (AFMA) and reported in a trade publication [Ray, 1965]. From 1955, the West North Central region showed a sharp increase in turkey production, a strong increase in beef production and some increase in milk production; substantial decreases were noted for hogs and egg production. In 1964 Iowa easily led other states in hog production but was overtaken by California in egg production so ranked second in 1964 after having been first in 1955.

The AFMA conducts a tonnage reporting service by gathering information from member manufacturers who choose to cooperate. Over 100 companies cooperate -- they distributed 21.5 million tons in 1966. Information is gathered on bulk versus bagged handling and complete versus supplement feed form. Until 1960, when the AFMA survey began, there were few detailed statistics on these two important product-form relationships. Nationally, the percentage of total tonnage which was complete feed declined slightly from 68 percent in 1960 to 66 percent in 1966; the decline in the West North Central region was from 42 to 37 percent [AFMA, Market Research Bulletin, various issues]. This percentage varies with livestock class; it is lowest for hogs, beef and sheep. The U.S. proportion of feed handled as bulk increased sharply from 38 percent in 1960 to 57 percent in 1966; however, the West North Central proportion is lower in both increase and absolute level at 25 and 39 percent respectively.

The preceding discussion implicitly suggests two sources of feed industry trends. Some trends result from rapid demand expansion. However, other trends such as increasing demand orientation would be expected to evolve even if the absolute demand level had remained relatively constant. The American feed industry is growing in both size and complexity. The past, present and future trends can be expected to affect the structure of the industry.

D. Feed Industry Structure and Organization

The primary concern of this section will be the market structure of the commercial mixed-feeds industry. While a market may be defined as a sphere encompassing a closely interrelated group of buyers and sellers, structure refers to the interrelations *per se* [Bain, 1965, p. 7]. In the present study market structure will refer to organizational characteristics of the market including the nature and extent of intra-buyer and intra-seller relationships and the relationships between them. These characteristics influence the nature of competition and pricing within the market. Important dimensions of market structure include the number and relative size of market participants and the degree of product differentiation in the market. In the feed industry, primary attention is directed toward feed manufacturers as buyers (input market) for feed grains and other ingredients and as sellers to livestock producers.

The market organization of the industry is depicted in Figure 2. This is a flow chart illustrating the physical movement of materials

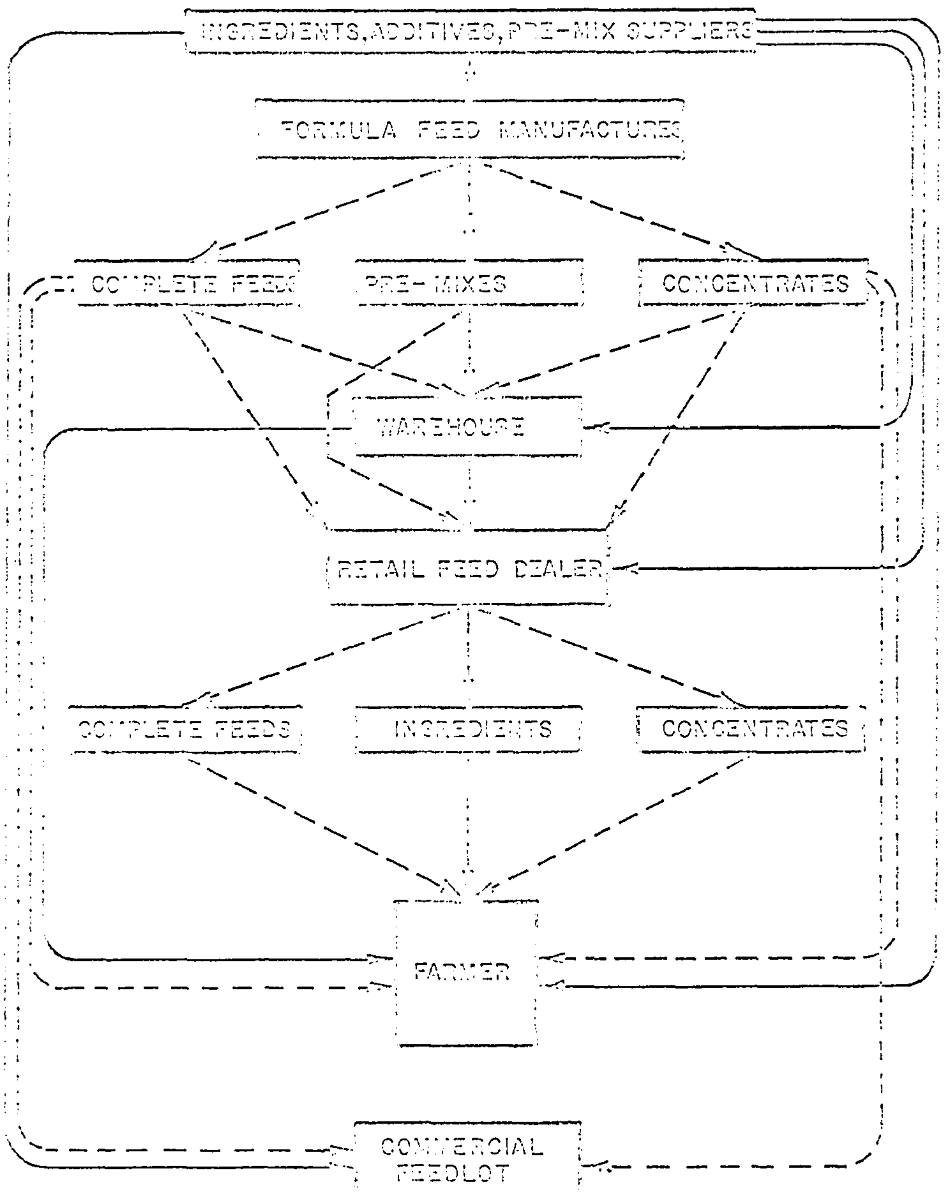

Figure 2. Market organization of the feed industry

in the sphere of feed production and distribution. The dollar flow would be opposite in direction. In a context of methodology familiar to economists, the market organization flow chart could be visualized as an input-output model or a combined assembly-disassembly model. The trends discussed in the previous section could result in basic structural changes in the flow chart. Most, however, would affect magnitude of flows within the basic structure. For example, the trend toward direct selling would be represented by a heavier flow along the arrow from "formula feed manufacturers" (complete feeds and/or concentrates) to "farmers" and/or "commercial feedlot."

The input market consists of feed grains, animal and plant protein materials and trace ingredients such as minerals, vitamins and antibiotics. Most protein ingredients are industrial by-products. Product differentiation at the input level is nearly nonexistent; standardized government grades and a high level of market information result in the output of one seller to be regarded as very similar to that of any other.

Iowa is a surplus state with reference to corn. The USDA computes the feed grain balance situation for each year [USDA Statistical Bulletin No. 337, 1963 and annual supplements]. This is done by subtracting estimated feed grains fed to livestock and deducting from total production. With infrequent exception, all states bordering Iowa are feed grain surplus states. Virtually the sole plant protein source utilized in Iowa is the soybean. About two-thirds of U.S. soybeans are produced in the Midwest; only Illinois ranks above Iowa in state production [USDA Fats and Oils Situation, 1967]. In a study of the soybean industry, J. W. Uhrig suggests reasons to expect increased soybean production in Iowa [Uhrig, 1965]. In 1964, of 20.2 million crop acres harvested in Iowa, 51 percent was corn and 21 percent soybeans [Iowa Crop and Livestock Reporting Service, 1964, p. 10]. The markets for other input ingredients are more regional in nature. Since the major ingredients are likely to be available locally with reference to feed ingredients, plants located in one part of the state should be competitive with other parts.

Manufacturing costs and attendant economies of scale considerations are detailed at a later point in the present study.

With reference to plants, as distinct from firms, the scope of the market for manufactured formula feed products is narrower than the market for inputs. The relevant trade areas for output is substate. The distribution system is more complicated; typically a superstructure of distributive institutions exists between the feed manufacturer and the livestock producer. Feed buyers are widely scattered in space and so are isolated spatially from many feed production sources. Despite the increases in direct selling, the dealer distribution system retains a crucial role in the feed industry.

Concentration refers to ownership or control of a large proportion of some aggregate of economic resources or activity either by a small proportion of the firms or by a small absolute number of such firms [Bain, 1965, p. 85]. Degree of concentration frequently is used as an indication of monopoly or oligopoly. Scant available data suggest a relatively low degree of concentration in the prepared animal feeds industry. Table 3 indicates concentration in terms of value of shipments. The feed industry would fall into Bain's "Type V" category of

Table 3. Percent of value of shipments by the largest feed companies, 1954 and 1958[a]

SIC code	Class of product and year	Percent of value of shipments accounted for by		
		Largest 4	Largest 8	Largest 20
2042	Prepared animal feeds:			
	1954	21	29	43
	1958	22	31	44
20421	Poultry feeds:			
	1954	26	36	52
	1958	26	37	52
20422	Livestock feeds:			
	1954	23	33	48
	1958	26	36	51

[a]Source: U.S. Senate, 1962.

the continuum between monopoly and pure competition. The characteristics of this category are less than 35 percent of the market controlled by the largest four firms and less than 45 percent by the largest eight; an industry in "Type V" is described as one having some large firms with a very extensive competitive fringe of small sellers [Bain, 1965, p. 131]. The flour industry would fit into the same category. According to Bain's analysis, the feed industry would harbor few elements of oligopoly. The data cited are national in scope. At local or regional levels, it seems likely that the feed industry is more concentrated.

The feed industry seems to fit into this theoretical capsule fairly well. Industry competition includes firms ranging from large with regional or national distribution to locally oriented smaller suppliers. The former tend to emphasize nonprice competition through product development and quality control (product differentiation) and advertising. The competitive fringe of small firms try to achieve volumes by price competition and cost reduction. The magnitude and impact of product differentiation seems to be relatively slight and may be decreasing. One study found that purchasers of local feeds generally were price-conscious, had larger operations, were indifferent to advertising claims, were interested in convenient supply location and services, and many purchased directly [Kalb, 1964]. As farms become fewer in number but larger, an increasing emphasis on price competition can be anticipated. Feed manufacturers advertise little in newspapers or network television -- probably directing advertising expenditure toward farm magazines, local television and point of purchase media [Padberg and Nelson, 1965].

Apparently farmers are becoming more price-conscious. To what degree will the feed industry be influenced toward aggressive price competition? The degree depends not only on the price-consciousness of feed buyers but also on the expectation of how competing feed firms will react. Aggressive price competition seems prevalent in the competitive fringe and the nonprice competition of large firms is cushioned and somewhat redirected toward price competition by the dealer distributive superstructure between the manufacturer and

and the eventual product user. However, most analyses and data available are highly aggregative in nature. It is very likely that data from substate trade areas would show higher market concentrations. As a result, price competition would be relatively subdued.

E. Recent Trends in Iowa Agriculture

Changes being undergone in Iowa agriculture are exemplified by comparing 1959 and 1964 Census of Agriculture results. Several of these changes have impact upon the commercial mixed-feeds industry in the state. A comparison of state and national trends is useful since Iowa agriculture is a subset of the national agricultural situation just as the Iowa feed industry should be evaluated in a context of the national industry. Such comparisons generally are more useful in a first difference rather than absolute basis.

In the five-year span, Iowa farm numbers continued to decline while farm size and farm values continued to increase [Census of Agriculture, 1954, 1959 and 1964]. Farm numbers fell from 174,707 to 154,162 (12 percent) as size rose from 193.6 to 219.0 acres per farm (13 percent) and value rose from $49,150 to $59,901 per farm (22 percent). Two-thirds of the farm value increase was due to increased size of farms with the remainder representing increasing value per acre of land and buildings [Mayer and Howell, 1966]. Between 1959 and 1964 the per farm value of all farm products sold went up from $13,074 to $16,848 (29 percent). Between 1954 and 1959, the four respective percentage changes were 9.5, 9.7, 39 and 37.

More regular hired workers were retained in 1964 as compared to 1959, yet total labor decreased because of fewer farm operators. On the other hand, capital inputs and commercial expenditures such as for fertilizers, herbicides and insecticides increased. A capital-for-labor factor substitution trend is detected at the farm level.

In the same time period, total cropland harvested was off somewhat while the livestock picture was mixed. Census figures show that corn acreage and production fell considerably while that of soybeans nearly doubled. Beef cattle and turkey production increased. Other kinds of poultry were off as were sheep. Meanwhile swine and dairy production remained about steady.

Examination of national census data for 1964 and 1959 suggests that Iowa trends are in step with national agricultural trends. Farm numbers decreased while farm size, farm values and gross sales per farm were up. The tendency for reduced cropland also held for national figures; interpretation at either level (national or state) must consider the influence of government programs. Iowa livestock production trends corresponded to national trends except that all major farms of poultry production were up sharply in 1964 national figures as contrasted with 1959.

Looking to the future, Iowa's population is not expected to change a great deal. While Iowa's population is expected to expand less than 3 percent in the next decade, the rate of increase for the United States is expected to be about 15 percent [Current Population Reports, 1967]. In a projection study for Iowa, Maki predicted a 1975 population just under three million noting that increases in manufacturing and service industries will be able to do little more than offset employment declines in agricultural production [Maki, 1965]. However, for livestock products consumption it is national population and preferences which is of primary importance. And so it is for the feed industry. U.S. population has been increasing at roughly 2 percent per year. Iowa agricultural output in 1974 has been predicted at one-quarter higher than 1964 -- largely based on population projections. Maki projects production increases for meat animals, feed crops, poultry, eggs and dairy products but decreasing employment in each of these production activities. The employment decreases will result because increases in final demand generally are less than increases in labor productivity.

What are the changes in the Iowa feed industry that have taken place in the wake of changes in its basic agriculture? One indicator is feed tonnage volume. Feed manufacturers operate within the regulatory framework set forth by the Iowa Feed Law [Iowa Feed Law, 1966]. The law is administered and enforced by the Secretary of Agriculture and the Iowa Department of Agriculture. Among the provisions of the law are requirements for registration, licensing and payment of inspection fees. All commercial feeds must be registered. Any person or entity that manufactures, mixes or mixes to customer order must obtain a license. All commercial feeds distributed in Iowa are subject to an inspection fee of ten cents per ton.

The Iowa Department of Agriculture, Feeds Division, compiles and publishes a report of feed tonnages taxed by means of the inspection fee. The data are compiled twice per calendar year. The contents of the reports have varied somewhat; minor adjustments or estimates had to be made for several years in order to achieve data comparability. The commercial feed tonnage data for 1954 through 1965, after adjustments, are presented in Table 4. Supplement and complete feed tonnages are totaled separately for several major livestock classes.

Yearly tonnage has about doubled since 1954 -- with increases in all feed classes except chicken feed. Turkey and beef tonnages have increased sharply. Feed production for swine and dairy increased strongly up to about 1959-1960, whereupon swine tonnage became steady and dairy feed tonnage continued to increase moderately. These state-developed tonnage figures are more useful for noting trends and indicating the product form breakdown (supplement versus complete feeds) than as indicators of total tonnage. In reality the tonnage figures represent tonnage taxed. Nevertheless, the data support a statement that commercial feed supply in Iowa is expanding to fulfill increasing demand.

A USDA study of the feed industry in selected states (including Iowa) noted that national trends and Iowa trends are closely in step [Vosloh and Brensike, 1961]. In an industry experiencing demand expansion, a primary manner of adjustment to trends is the mode of capacity expansion. FEED AGE made a survey to ascertain the nature and magnitude of 1963 feed facility expansions in the United States [Karstens, 1964]. The expansions were relatively small since less

Table 4. Commercial feed tonnages for Iowa, 1954 to 1965[a]

No.	Item	1954	1955	1956	1957	1958	1959
1	Chicken feeds complete	172,371	151,761	269,549	220,231	195,302	151,901
2	Chicken feeds supplement	181,232	258,188	247,746	240,664	258,129	248,729
3	Turkey feeds complete	42,912	37,781	47,126	45,472	81,619	57,083
4	Turkey feeds supplement	26,082	37,157	50,407	57,976	67,219	68,806
5	Swine feeds complete	154,546	150,192	127,367	202,222	334,968	338,814
6	Swine feeds supplement	333,427	469,109	373,865	423,485	554,419	562,222
7	Beef feeds complete	37,662	44,727	49,930	22,186	55,054	28,139
8	Beef feeds supplement	103,821	193,935	231,333	244,524	337,120	366,502
9	Dairy feeds complete	11,983	14,795	19,801	10,299	14,250	14,450
10	Dairy feeds supplement	32,901	57,756	39,856	59,347	66,295	62,868
11	Calf feeds	20,193	11,155	10,851	14,298	24,420	26,658
12	Sheep feeds all types	549	2,248	2,121	1,548	3,597	4,023
13	Horse feeds all types	70	1,093	367	472	1,105	543
14	Total reported tonnages	1,117,748	1,429,895	1,470,367	1,542,722	1,993,494	1,930,733

[a]Source: Iowa Department of Agriculture Feed Tonnage Reports, various years.

Table 4. Continued

No.	Item	1960	1961	1962	1963	1964	1965
1	Chicken feeds complete	149,170	163,791	146,574	128,965	119,499	110,033
2	Chicken feeds supplement	241,830	224,680	209,306	196,833	182,386	167,938
3	Turkey feeds complete	73,048	90,101	57,294	51,935	53,583	55,232
4	Turkey feeds supplement	66,161	89,769	82,373	84,796	87,488	90,180
5	Swine feeds complete	261,961	370,125	394,567	401,025	403,027	405,030
6	Swine feeds supplement	562,371	656,385	750,496	826,071	830,196	834,322
7	Beef feeds complete	23,294	66,172	89,234	62,098	65,071	68,044
8	Beef feeds supplement	345,156	374,293	385,102	452,833	474,513	496,193
9	Dairy feeds complete	13,188	18,267	19,026	17,238	18,158	19,079
10	Dairy feeds supplement	69,909	66,956	68,251	73,693	77,627	81,561
11	Calf feeds	30,652	18,927	20,842	20,254	21,335	22,416
12	Sheep feeds all types	4,118	3,576	4,580	3,509	3,677	3,845
13	Horse feeds all types	582	1,185	1,038	1,234	1,234	1,234
14	Total reported tonnages	1,841,436	2,144,222	2,228,676	2,320,479	2,337,790	2,355,103

than one-third of the 341 expansions recorded involved capital expenditures in excess of $125,000. The significance of the survey to the present study is that Iowa accounted for nearly one-fifth of all the expansions.

As part of the present study, a survey was taken of expansions in the North Central region reported by FEEDSTUFFS. 1960 through 1964 (five years) were covered. The observations included expansions at all levels -- manufacturing and local elevators. Besides new facilities, some expansions were expansion by remodeling and some were additions to existing facilities. Of the 245 reported expansions, 78 or 32 percent were in Iowa. Of the Iowa expansions, 36 percent were by cooperatives and 49 percent by private operators or firms. Large companies expanding by remodeling or building anew accounted for the remaining 15 percent. Nearly all (85 percent) were recorded as being new facilities as distinct from remodel-and-expand undertakings. It was not possible to obtain information indicating the magnitude of net expansion. One would likely err to assume all new constructions represent net feed industry capacity expansions. Often an old facility is abandoned as the new facility becomes operational.

F. Terminology and Technical Information

Even the term "commercial mixed-feeds industry" is subject to some uncertainty as to its meaning and scope. Its definition is of importance as discussions progress from generalities to detailed analysis. In the present study the definition will revolve about the activities of the feed manufacturer. Activities included are ingredient procurement, the manufacturing function and distribution including sales-related activities. The scope of the present study's definition is restricted to livestock and poultry feeds. This scope restriction is less inane than it first appears inasmuch as the Iowa Feed Law defines commercial feed with reference to all animals other than man.

Some of the terminology common in the feed industry is self-evident only to industry people. Many of these terms will be used in the ensuing analysis. Explicit explanations should be helpful. An industry definitions committee had been formed and most terminological explanations which will follow draw upon their report [Poundstone, 1962, pp. 15-17].

Commercial feed: Materials which are distributed for use as feed or for mixing in feed for livestock and poultry production animals.

Feed ingredient: Each of the constituent materials making up a commercial feed.

Formula feed: Two or more ingredients proportioned, mixed and processed according to specifications.

Commercial formula feed: A formula feed processed to the specifications of the manufacturer.

Customer formula feed: A formula feed processed to the specifications of the final purchaser -- may or may not contain a portion of commercial formula feed.

Complete feed: A complete ration capable of sustaining life, growth and/or production without any additional feed being consumed (except water).

Supplement: A commercial feed which requires the addition of other feed ingredients to farm a complete feed.

Pellets: Agglomerated feeds formed by extruding an individual ingredient or mixtures by compacting and forcing feed through die openings by a mechanical process.

Micro-ingredients: Added vitamins, trace minerals, antibiotics, drugs and other materials normally required and used in small quantities.

Premix: A combination of one or more micro-ingredients with diluent(s).

Mixing: Agitating feeds or ingredients until the dispersion reaches a pre-determined specific degree of uniformity.

Grinding: The reduction of particle size by impact, shear or attrition.

The term "concentrate" historically has been a synonym for supplement. The industry definitions committee recommends elimination of the term. However, in the present study it will be defined as a term which refers to collective tonnages of supplement and complete feeds. For example, the Iowa Department of Agriculture reports tonnages of supplement and complete feed; the sum of these tonnages (for a livestock class total or a state total) will be known herein as concentrates.

III. ECONOMIC THEORY CONTEXT OF THE STUDY

In the genesis of economic theory, agriculture was the framework for thought. David Ricardo was concerned primarily with the economic role of land as a fixed natural resource. The diminishing returns conception soon developed. For nascent industry the agriculturally derived economic theory seemed to apply. But later theory had to account for the realities of an industrial economy capable of constant and even increasing returns.

From early economic theorists to the present, there has been an important shift in benchmark (if not emphasis) from supply to demand. The basing point has become identification and quantification (and often stimulation) of consumer demand followed by production to fulfill it. When diminishing returns in production was linked to diminishing marginal utility in consumption, the ingeniously symmetrical Walrasian system was conceived. The essential conditions of the Walrasian system are: a fixed factor-variable factor production relationship (supply), a counterpart marginal schedule in the psychology of consumption (demand) and a close physical connection between them [Baumol, 1965, pp. 340-342].

A. Consumer Theory

Utility can be thought of as the subjective benefit a consumer accrues from possessing something he desires. Let us assert a context of rationality for the consumer. The rationality postulate requires the consumer to rank his alternatives; axioms of preference, choice and transitivity are implicit to the ranking requirement. The ranking of alternatives (commodities) is expressed mathematically by the utility function.

The graphic conception of a utility function is an indifference curve. Only ranking is required (ordinality) rather than how much one alternative is preferred to another (cardinality). Using the assumption of ordinal utility measure, the theory deducing utility functions, indifference maps and demand curves is well developed [Hicks, 1946, ch. I; and Baumol, 1965, pp. 180-202]. The consumer usually is assumed to possess complete knowledge. The utility function is defined with reference to consumption during a specified period of time (static); the period of time during which the utility function pertains should be long enough to allow for variety but too short for changes in tastes [Henderson and Quandt, 1958, p. 9].

It is assumed that the consumer seeks to maximize his utility function within the constraints imposed by his resource limitations. Suppose the consumer has full knowledge of his commodity alternatives, their prices and his budgetary constraints. The consumers ordinal utility function can be expressed as:

$$u = u(q_1, q_2, \ldots, q_n) \tag{3.A.1}$$

where q_i are the quantities of commodities Q_i consumed; $i = 1, 2, \ldots, n$. The budgetary constraint, M,

$$M = \Sigma_{i=1}^{n} p_i \, q_i \tag{3.A.2}$$

limits the absolute level of utility, u, which can be realized. M is the budget available to the consumer while p is the price vector corresponding to the commodity vector q. The properties of demand functions can be derived using differential calculus when the utility function, u(q), is assumed to be continuous with existing first- and second-order partial derivatives.

A convenient mathematical procedure for maximization of the constrained utility function involves the Lagrangian multiplier technique. Equations 3.A.1 and 3.A.2 can be combined into a new expression, V, to be maximized.

$$V = u + \lambda \ (M - pq) \qquad (3.A.3.a)$$

or

$$V = u \ (q_1, \ldots, q_n) + \lambda \ (M - \Sigma_{i=1}^{n} p_i \ q_i) \qquad (3.A.3.b)$$

It can be proven mathematically that maximization of V implies maximization of u. The system contains n + 1 unknowns.

The solution is calculated by setting the partial derivatives of V with respect to q_i and λ equal to zero. A system of n + 1 equations results and permits solving for the n + 1 unknowns. To wit:

$$\begin{aligned} \partial V/\partial q_i &= \partial u/\partial q_i - \lambda p_i = 0 \\ \partial V/\partial \lambda &= M - \Sigma_{i=1}^{n} p_i \ q_i = 0 \end{aligned} \qquad (3.A.4)$$

The first-order condition for utility maximization is that the ratio of marginal utilities must equal the price ratio:

$$\frac{\partial u/\partial q_j}{\partial u/\partial q_k} = \frac{p_j}{p_k} \qquad (3.A.5)$$

where j and k refer to any pair within the range of i. Further, the condition can be restated as equal ratios of marginal utility divided by price:

$$\frac{\partial u/\partial q_j}{p_j} = \frac{\partial u/\partial q_k}{p_k} \qquad (3.A.6)$$

This ratio gives the rate at which satisfaction would increase if an additional dollar were spent. The Lagrange multiplier, λ, is interpreted as the marginal utility of income -- the utility gained from the last dollar spent. Notice that $\partial V/\partial M = \lambda$ and that $\lambda > 0$.

The second-order condition for a constrained maximum requires that the bordered Hessian determinants alternate in sign. The elements of the bordered Hessian are second-cross partial derivatives, u_{jk}, or $\partial^2 V/\partial q_j \partial q_k$ and two price vectors. Hence:

$$(-1)^n \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1n} & -p_1 \\ u_{21} & u_{22} & \cdots & u_{2n} & -p_2 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ u_{n1} & u_{n2} & \cdots & u_{nn} & -p_n \\ -p_1 & -p_2 & \cdots & -p_n & 0 \end{bmatrix} > 0 \qquad (3.A.7)$$

In the simplest case, and commodity, maximizing the utility function would require a negative second derivative at the critical point. The second-order condition implies that indifference curves are convex from below. They are seen to be negative in slope when the total derivative of the slope is taken [Carlson, 1939, p. 20]. Intuitively, comparing first-order conditions and the substitution rate illustrates the sign of the indifference curve slope. The rate of commodity substitution is derived as follows:

$$du = \Sigma_{i=1}^{n} \partial u/\partial q_i \, dq_i = 0 \qquad (3.A.8)$$

then

$$\frac{\partial u/\partial q_j}{\partial u/\partial q_k} = - \frac{dq_k}{dq_j} . \qquad (3.A.9)$$

From the analysis of utility maximization, the consumer's demand curve can be derived. The demand curve conceives of quantity as a single-valued function of income, the specific commodity's price and prices of other commodities desired:

$$q_i = D\ (p_1, p_2, \ldots, p_n, M) \qquad (3.A.10)$$

where $i = 1, 2, \ldots, n$. The respective quantities are solved from the n+1 first-order condition equations. Demand functions can be shown to be homogeneous of degree zero in prices and income; that is, quantity remains unchanged if all prices and income change in the same proportion [Henderson and Quandt, 1958, p. 21].

Basic consumption function theory can be traced from the Keynesian absolute income hypothesis to the familiar permanent income hypothesis via the relative income hypothesis. The Keynesian formulation offers consumption as a function of absolute real income with the marginal propensity to consume (MPC) positive but less than unity and MPC < APC; both MPC and APC decline as income rises [Ackley, 1964, pp. 218-219]. This Keynesian formulation is short-run in nature and suggests a non-proportionality relationship between consumption and income. Empirical results, however, indicated that the APC had remained relatively constant albeit incomes (total and per capita) had risen substantially [Ackley, 1964, pp. 238-240]. A proportionality relationship (MPC = APC) seemed to hold.

A relative income hypothesis was developed suggesting a strong psychological interdependence among consumers and that consumers adjust their consumption to both current and previous income levels [Duesenberry, 1949]. It was hypothesized that consumption increased as a "ratchet effect" and that savings were residual.

The permanent income hypothesis suggests that the apparent short-run nonproportionality merely reflects a lag in consumption adjustment to short-term income fluctuations. It concurs that a stable and predictable relationship exists between consumption and income and that this relationship is proportional. But the permanent income hypothesis is that the relationship is between permanent, as distinct from transitory, components of measured consumption and income [Friedman, 1957].

B. Firm Theory

The usual point of departure in analyzing the theory of the firm is to establish the objectives of the firm. The firm is a producing unit. In general, economic theory assumes that the firm produces its output seeking to meet an objective of profit maximization. Recall that the consuming unit sought to maximize utility. Profit maximization is constrained by given technology and the resources available to the firm. It is not generally agreed that profit maximization is the objective of the firm. In fact, Baumol has suggested sales maximization constrained by profit level [Baumol, 1965, pp. 301-303]. Earlier, T. Scitovsky had stressed the "satisfaction" objective [Scitovsky, 1952]. More recently, firm objectives have been reconsidered in a context of utility maximization [Williamson, 1964; and Alchian, 1965]. In a recent survey article, Professor Machlup suggests including two or three objectives (presumably weighted) in a single quanitifiable one -- merging marginalism with managerialism by integrating money profits with other goals into one formula of "maximizing behavior" [Machlup, 1967]. Perhaps profit maximization should be regarded as a summary objective approximating reality for the preponderance of firms while important exceptions are recognized.

The competitive framework within which a firm must operate is exceedingly relevant. On the output (input) side, the possible range is from pure monopoly (monopsony) to pure competition. Common competitive frameworks lying between these extremes are oligopoly (oligopsony) and monopolistic (monopsonistic) competition. In pure competition the firm's quantity of outputs and inputs affects the price of neither. Any deviation from pure competition is detected by a quantity-to-price causal relationship. On the output side, marginal revenue (MR) becomes

$$MR = d(TR)/dY = Py + Y \cdot dPy/dY \qquad (3.B.1)$$

where total revenue is $TR = Py \cdot Y$ and Py is the price of output Y. Correspondingly, on the input side marginal cost (MC) becomes

$$MC = d(TC)/dX = Rx + X \cdot dRx/dX \qquad (3.B.2)$$

where $TC = Tx \cdot X$ is total cost and Rx is the price of input X. Under profit (π) maximization where $\pi = TR - TC = P \cdot Y - R \cdot X$, calculus suggests $d\pi/dX = 0$ as the procedure to solve for the profit-maximizing level of output (output level is altered by changing the input level). The familiar MR = MC profit maximization condition follows from the summary equation

$$d\pi/dX = 0 = Py \frac{dY}{dx} + Y \cdot \frac{dPy}{dX} - Rx - X \cdot \frac{dRx}{dX} \qquad (3.B.3)$$

by algebraic manipulation. If pure competition prevails, terms 2 and 4 on the right-hand side of Equation 3.B.3 are null. Some monopoly (monopsony) power by the firm is denoted by positive magnitude in term 2 (4). If both, all four terms have positive values.

The production economics analysis which follows will assume perfectly competitive product and factor markets. It is static while assuming the absence of risk and uncertainty. Differential calculus can be used if the production function is assumed to be a continuous with continuous first- and second-order partial derivatives. These assumptions are made although production functions may be discontinuous and may be a system of equations rather than a single function. The features of production theory have been demonstrated using linear activity analysis [Koopmans, 1957]. Thus overcome are two weaknesses inherent in the restrictions accompanying analysis by differential calculus: myopia and inability to handle inequalities, as distinct from equations. The discussion will be facilitated by assuming the restrictions implied by differential calculus do hold.

The production function circumscribes the technical, causal relationship between input (factor) and output (product) quantities. The factors and products are conceived as flows and their rates refer to the same unit of time. The production function presupposes technical efficiency: maximum output with given input and/or minimum input for given output. It is defined in a time period or "length of run" context relating not to calendar time but to inputs held fixed at predetermined levels. The "long run" is finite to the extent of sheltering technology from improvements yet allowing time to complete technical processes. The "short run" is defined by an additional restriction on the long run, namely that the entrepreneur is unable to alter the levels of certain fixed inputs. Expressing mathematically, the long-run production function is $Y = Y(X_1, X_2, \ldots, X_k, \ldots, X_{n-1}, X_n)$ where all factors of production are variable. In the short run only some can be varied and output level is conditional upon the fixed input levels (denoted by bar) as well, thus:

$$Y = Y(X_1, \ldots, X_k, \bar{X}_{k+1}, \ldots, \bar{X}_n)$$

where X_1 through X_k are variable and the others fixed. The major difference between short- and long-run analysis is the number of variable inputs; nearly all short-run results apply, with slight alterations, to the long-run period [Henderson and Quandt, 1958, p. 44].

The short-run profit equation for a single product can be represented by

$$\pi = P \cdot Y - \sum_{i=1}^{k} R_i X_i - F \tag{3.B.4}$$

where F is the fixed cost of predetermined inputs and Y is the production function $Y = Y(X_i)$. The first-order condition for profit maximization is found by differentiating 3.B.4 by each X_i and setting the result equal to zero

$$\frac{d\pi}{dX_i} = P \cdot \frac{\partial Y}{\partial X_i} - R_i = 0 \tag{3.B.5}$$

so $P \cdot \partial Y/\partial X_i = R_i$ for $i = 1, 2, \ldots, k$. In words, the marginal value product equals the marginal cost. The optimum factor-factor combination can be found by taking the total differential of isoquant $Y^o = \phi\ (X_i)$, obtaining

$$dY^o = 0 = \frac{\partial Y}{\partial X_1} \cdot dX_1 + \ldots + \frac{\partial Y}{\partial X_k}\ dX_k \tag{3.B.6}$$

or

$$\frac{\partial Y/\partial X_i}{\partial Y/\partial X_j} = - \frac{dX_j}{dX_i} .$$

As the level of the isoquant Y^o (output) is varied, Equation 3.B.6 defines the expansion path -- the optimal combinations of inputs for any output level. Manipulating 3.B.5 we obtain

$$\frac{\partial Y/\partial X_i}{\partial Y/\partial X_j} = \frac{R_i}{R_j} \tag{3.B.7}$$

and comparing to 3.B.6 the result

$$\frac{R_i}{R_j} = \frac{dX_j}{dX_i} \tag{3.B.8}$$

requires equal slopes of the factor price line and the isoquant. The slope is negative within the ridge lines defining the zone of rational production.

The parallel between consumer and production theory continues as second-order conditions are considered. Again, the principal minors of the relevant bordered Hessian determinant must alternate in sign starting with $\partial^2\pi/\partial X_1{}^2 < 0$. That is, under profit-maximizing conditions, the magnitude of profit from each additional unit of each factor input must be decreasing but positive.

Generalizing to the firm which can produce m products using k factors, a vector containing each can be conceptualized where there are m positive elements (output) and k negative elements (input). Such a vector Γ would appear as

$$\Gamma = \{Y_1, Y_2, \ldots, Y_{m-1}, Y_m, -X_1, -X_2, \ldots, -X_{k-1}, -X_k\}. \quad (3.B.9)$$

A corresponding coefficient vector of prices and costs would be

$$P = \{P_1, P_2, \ldots, P_{m-1}, P_m, R_1, R_2, \ldots, R_{k-1}, R_k\}. \quad (3.B.10)$$

The solution takes the form of maximizing the scalar $P\Gamma'$ subject to the implicit production function $\theta(\Gamma) = k$. Using Lagrangean multipliers, the equation

$$L = P\Gamma' + \mu\,\theta(\Gamma) \quad (3.B.11)$$

is differentiated partially with respect to Γ and the Lagrangean multiplier μ. The result is

$$\begin{aligned} \partial L/\partial\Gamma &= P + \mu\,\partial\theta/\partial\Gamma = 0 \\ \partial L/\partial\mu &= \theta(\Gamma) = 0 \end{aligned} \quad (3.B.12)$$

The first-order conditions indicate the usual factor-factor and factor-product relationships requisite to profit maximization. In addition, the product-product relationship is specified. Manipulation of the first m equations in 3.B.12 yields

$$\frac{\partial\phi/\partial\varepsilon}{\partial\phi/\partial\alpha} = -\frac{\bar{P}\alpha}{P\varepsilon} \quad (3.B.13)$$

where $\partial\phi/\partial\varepsilon$ and $\partial\phi/\partial\alpha$ are partials of any two alternatives of an explicit function the same as $\theta(\Gamma)$ except minus one product element, and where $P\alpha$ and $P\varepsilon$ refer to P except for the respective price element. This is the familiar procedure of drawing tangent product price ratios to the production possibility curve. In words, for any two products their price ratio must equal their marginal rate of substitution if profits are to be maximized.

C. Conventional Cost Theory

Cost functions can be derived from the production theory considered above. The relevant short-run system of equations, in matrix notation, would be

$$Y = f(X) \tag{3.C.1}$$

$$TC = R'X + K \tag{3.C.2}$$

$$0 = g(X) \tag{3.C.3}$$

representing the production function, the cost equation and the implicit expansion path function. The rational entrepreneur will select input combinations which lie on his expansion path. The long-run system is

$$Y = f(X,E) \tag{3.C.4}$$

$$TC = R'X + Y(E) \tag{3.C.5}$$

$$0 = g(X,E) \tag{3.C.6}$$

where E denotes a continuous scale variable.

Consider the cost functions in more detail. Variable, fixed and total average costs are determined by dividing output quantity into the first, the second and the sum of terms on the right-hand side of cost Equations 3.C.2 and 3.C.5. Marginal cost (MC) is the first derivative of total cost (TC). In the short run MC of total and total variable costs are equal, but in the long run the scale (E) can also be varied. The long-run average cost curve (LRAC) is an envelope of the short-run average cost (SRAC) curves. The analogy for marginal cost curves does not hold. The long-run marginal cost (LRMC) curve may be defined as the locus of those points on the short-run marginal cost (SRMC) curves which correspond to the optimum plant size for each output.

Total cost is illustrated as a cubic function of output. The shape of MC and AC can be derived from the TC function. The form of these functions, as developed in "received" cost theory, is depicted in Figures 3A and 3B. The depiction refers to a specific plant size. The quantity relationships in each figure (Oa and Ob) between the total and other cost functions are shown. The average total cost is the vertical summation of average variable and average fixed costs (not shown). Under pure competition the entrepreneur would equate his selling price to marginal cost. The supply curve would be a step function along the dependent axis until the ATC minimum is reached (assuming an unwillingness to accept loss) whereupon the supply function becomes the MC curve. But profit maximization (in the sense of loss minimization) would tell the entrepreneur to operate as long as price does not fall below the minimum point on the AVC curve. Second-order conditions for profit maximization require the MC curve to be increasing, derived thus:

$$\pi = P \cdot Y - C(Y) \tag{3.C.7}$$

$$d\pi/dY = P - C'(Y) \tag{3.C.8}$$

$$d^2\pi/dY^2 = - C''(Y) < 0 \tag{3.C.9.a}$$

or $$d^2(TC)/dY^2 > 0. \tag{3.C.9.b}$$

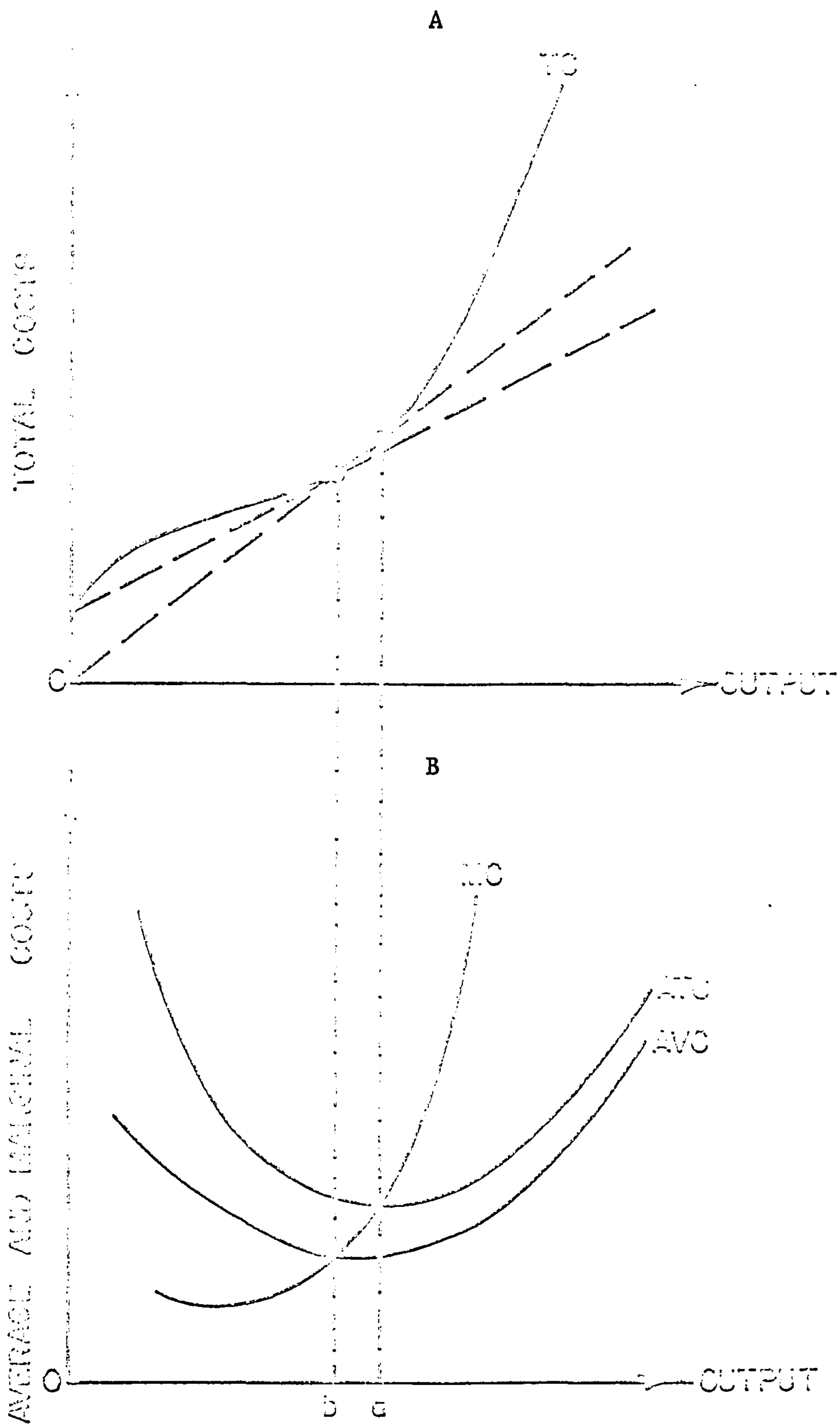

Figure 3. Total, marginal and average cost curves

The long-run cost function derivations from the short run have been discussed and are detailed in an important article [Viner, 1952]. A long-run adjustment is treated as a scale of operation adjustment along the expansion path. Carlson points out that if inputs are changed proportionally and input prices do not change, the cost development on the expansion path is determined solely by the character of the production function [Carlson, 1939, pp. 44-48]. The economies and/or diseconomies of scale depend on whether the production function point being considered is in the increasing, decreasing or constant returns zone of production.[1] In production economics this concept is dubbed the elasticity of production [Heady, 1961, pp. 49-50].

In general, theoretical arguments suggest that average cost functions have a U shape. However, there are grave difficulties involved in empirical application. Cost studies, along with some theorists, suggest that an L-shaped average function is more realistic. One analyst [Walters, 1963, pp. 39-46] has suggested that traditional cost theory seems more adequate for short-run and smaller-quantity (scale economies) ranges. A separate section of the present study will allude to some of the theoretical and empirical problems of cost function derivation and estimation.

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[1] $\frac{dY}{dX} \cdot \frac{X}{Y}$ is >, < or = unity, respectively.

D. Cost Theory: Extensions and Modifications

One of the major impediments in applying economic theory to business practice is the questionable relevance of the theoretical cost functions. Empirical results question the cost function shapes suggested by conventional economic theory. More than two decades ago one observer commented that empirical total cost-output relationships were nearly always found to be linear [Ruggles, 1941]. After an exhaustive survey, Walters drew two main conclusions about empirical cost functions: the long-run average cost function is L-shaped and not U-shaped, and the short-run marginal cost is constant [Walters, 1963, p. 46]. A book on the subject is iconoclastic in attacking the U-shaped short-run average cost curve; a linear total cost curve is proposed [Johnston, 1960]. Constant marginal cost is implied by a linear total cost function. If the total cost function is non-homogeneous (positive intercept) and linear, the average cost will be a declining function. There are a number of theoretical considerations, suggesting linearities, which are not a part of traditional economic theory.

1. Factor substitution and durables

Conventional theory would assume firm production with factors which are both substitutable and fully divisible [Brems, 1952, p. 578]. In terms of isoquants, substantial curvature, convex to the origin, is visualized. But in most manufacturing units the available degree of factor substitution is severely limited -- especially in the short run.

Once fixed equipment is installed, even the feasible range of substitutability between capital and labor is exceedingly narrow. The isoquants tend to be right-angle corners since the factors tend to be technical complements rather than substitutes. That is, a factor A increase gives impetus to output only in the presence of a proportional increase in factor B (factor B is limitational). Proportional relations among inputs tend to rule out the relevance of diminishing returns in the production function.

Durable factors are not fully divisible and are consumed over several production periods. This is in contrast to conventional cost theory which assumes factors of production to be exhausted in a single production period. While short-run maximization decisions should be based only on variable costs, long-run decisions must consider cost allocations for durables. Depreciation is usually charged by the "straight-line" method because of simplicity and taxation regulations.[1] Costs for interest on investment, insurance, taxes and maintenance services tend to be charged, in business accounting procedures, by simply dividing such costs by gross output volume. The total cost function tends to linearity under these circumstances.

2. The time dimension

Output can be increased without intensification of production. In many plants it is not difficult to extend the hours of operation

[1]Recent tax regulation revisions allow more complex and realistic depreciation formulas.

per day or week. Increasing unit costs result from increases in the rate dimension -- an intensification of output with a given set of productive facilities. Plants may meet peak demands by increases in both dimensions. To the extent that output is stepped up via increased hours of operation, total cost relationships tend toward linearity.

3. Discontinuities and segmentation

Plants often may increase output by exact duplication of facilities and attendant technically complementary inputs (such as an additional worker to operate each additional machine); no intensification is needed [French, Sammet and Bressler, 1956, p. 555]. This is segmentation. Increasing output by segmentation has linear but discontinuous implications on the total cost function. Segmentation adds to capacity in discontinuous steps and results in zones of excess capacity. Brems illustrates that profit maximization with a continuous parabolic total revenue function and a linear discontinuous total cost function generally will not occur at the MR = MC point. This point is detailed, using a step supply function, in a recent article [M. Kottke, 1967].

Discontinuities likely occur in both the rate and time dimensions. A firm will need to pay overtime and/or night shift increments in order to operate a number of hours beyond the day shift. Discontinuities in the rate dimension can result from adding an input "lump" to existing productive facilities.

4. Harmony in plant stages

A plant can be thought of as a unit turning out a product or set of products. With rare exception, a plant consists of several stages or sub-plants. Define a stage in terms of the aggregate input units designed to accomplish a certain transformation; the focal point of each stage is some major durable input [Brems, 1952, p. 577]. Stages are connected by transportation linkage and frequently by storage facilities.

A key element in studies of plant efficiency is the development of cost functions for each of the stages. Although segmentation is possible at the stage level as well as plant level, it is to within-stage production that traditional cost theory most adequately refers. There is a problem of "harmony" in organizing and coordinating several stages into efficient plant production. Why? Because the discontinuities represented by each stage differ in magnitude and length of production period. The problem is to ascertain a stage coefficient (common denominator) among plant stages which permits simultaneous operation of stages at minimum per unit cost levels. Least cost per unit of given plant output level is achieved by operating each plant stage at the minimum average cost rate of stage output.

5. The rate dimension

Armen A. Alchian has offered a volley of fresh ideas. His theoretical cost function reformulation focuses on two basic points: the rate dimension is only one of four characteristics affecting the cost-output relation, and costs may be defined as a change in equity [Alchian, 1959]. Alchian's results de-emphasize the importance of the rate dimension in cost theory.

Four characteristics influence cost and output. Rate of output is but one of the four. The other three are: total contemplated volume of output, time lag before initial production and programmed time profile of product availability. The characteristics are summarized in the equation

$$V = \Sigma_{T}^{T+m} \; x(t) \; dt \qquad (3.D.1)$$

where x(t), V, T and m are the four respective characteristics. Only three are independently assignable with the fourth then constrained.

Certain propositions regarding costs are suggested. The cost function can be expressed as

$$C = \Phi \; (V, x, T, m). \qquad (3.D.2)$$

Costs would rise with greater V and x; however, costs would increase at an increasing rate for rate of output ($\partial^2 C/\partial x^2 > 0$) but at a decreasing rate for volume ($\partial^2 C/\partial V^2 < 0$). Greater T and m decrease costs. A leading economist has suggested that Alchian's analysis is a basis for reconstruction of the firm's cost function [Hirshleifer, 1962]. The crucial point is a much weaker expectation of eventually rising marginal cost.

The cost concept used by Alchian refers to change in equity or present worth. Costs would be computed as change in equity over a period of time without including attendant change in income in the computation.

One incidental point: the cost-output relationship concepts have a strong analogy to concepts of investment theory. Investment and cost concepts have close relation in firm executives' and managers' planning and decision-making.

IV. LOCATION AND ECONOMIC THEORY

Many location theory principles closely parallel economic theory. Costs are a matter of prime concern and analysis inevitably rests on the principle of substitution. Location theory could be regarded as one segment of economic theory. Yet the efforts to generalize and extend static neoclassical theory have centered on the time dimension, while the spatial dimension has received relatively less attention. While location implicitly could be treated in marginalist theory by considering distribution as one of several cost sources, much is gained by treating location analysis explicitly.

A. Elements of Location Theory

There is a traditional dualism in location theory -- Weberian for industrial analysis and von Thunen for the agricultural sphere. The work of von Thunen, Weber and other location theorists has been reviewed frequently [Isard, 1956; Greenhut, 1956; and Beckmann and Marschak, 1955]. The Weber approach focuses on individual firm analysis primarily while that of von Thunen has been confined to aggregative analysis.

Von Thunen's problem was to answer a basic question: What is the pattern of land use in the territory surrounding an isolated and localized market for agricultural products? He postulated a population cluster within an evenly fertile plain where distances from the consuming center differ. The analysis consisted of a series of concentric zones of production in the area surrounding the city;

the production of each zone depended on its location relative to the city and product transfer costs.

In contrast, location of the individual firm was the direct concern of Weberian analysis. Three basic location forces were emphasized: transport cost differentials, labor cost differentials and agglomeration (deglomeration) economies (diseconomies) [Isard, 1956, p. 172]. Agglomeration factors have been classified as: large-scale interfirm economies, localization economies and urbanization economies [Hoover, 1948]. Weber's solution procedure was to construct contour lines (isodapanes) at the raw material and market sites. Each isodapane represented the locus of all points of equal transfer cost; minimum total transportation costs were to be determined directly. The method becomes very cumbersome as more than a few locations are considered. A partial equilibrium analysis was accomplished when Hoover combined relevant Weberian analysis with theory of the firm concepts. Hoover's contribution was in considering not only cost factors but demand determinants in plant location.

B. An Integration of Theories

The first major accomplishment in fusing location theory with general equilibrium analysis belongs to a German [Losch, 1954]. In the resultant general system, interrelations of spatially separated economic units were recognized and the analysis of location choices were couched in terms of spatial interdependence. A cogent summary is offered in a review article [Valavanis, 1955]. The bases of

Losch's ingenious exposition are demand cones and price funnels conceptualized as rotating triangles of the demand curve and the transportation cost plane in relation to their respective axes. Under stresses of competition, the topology of economic activities rearranges itself from circles to hexagons in shape.

Isard's analysis undertakes a generalization of Losch, Weber and von Thunen while integrating the combined location theories with economic analysis. The mathematical formulation is conceived assuming a continuous transport plane. A useful example, based on a more general mathematical formulation by Isard, has been worked out [Stollsteimer, 1961, pp. 27-30].

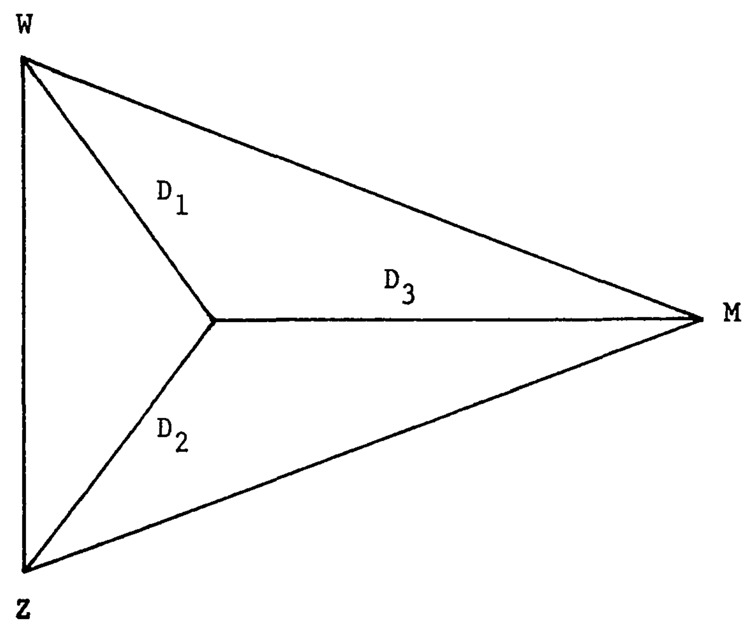

Figure 4. A locational triangle

In Figure 4 suppose W and Z are unique input sources for X_1 and X_2 used to produce Y which is sold at M. Assume all production costs except transfer costs are equal at all points surrounding W, Z and M; also, transfer costs are equal directionally from any point in the plane -- the cost minimization plant location will be in the location triangle. The plant location solution will depend on the values taken by D_i. The distance values are interrelated -- as illustrated by the function

$$D_3 = D_3 \, (D_1, D_2) \tag{4.B.1}$$

The production function

$$Y = Y(X_1, X_2 \mid X_3, \ldots, X_n) \tag{4.B.2}$$

is invariant to plant location. $X_3 \ldots X_n$ are inputs making up the fixed plant.

The total cost function

$$TC = \beta_o + \beta_1 X_1 + \beta_2 X_2 + b_1 X_1 D_1 + b_2 X_2 D_2 + b_3 \, Y \, D_3 \tag{4.B.3}$$

addends the conventional total cost function by adding transfer costs.

A Lagrangean expression can be formed to facilitate the solution. The expression is

$$L = TC + \lambda(Y^o - Y(X_1, X_2 \mid X_3, \ldots, X_n) + \mu(D_3 - D_3 \\ (D_1, D_2)) \tag{4.B.4}$$

and can be differentiated with respect to physical quantities, distances and multipliers, and the results set to null.

$$\frac{\partial L}{\partial X_1} = \beta_1 + \frac{\partial \beta_1}{\partial X_1} \cdot X_1 + b_1 \, D_1 + b_3 \, D_3 \frac{\partial Y}{\partial X_1} - \lambda \frac{\partial Y}{\partial X_1} = 0 \tag{4.B.5}$$

$$\frac{\partial L}{\partial X_2} = \beta_2 + \frac{\partial \beta_2}{\partial X_2} \cdot X_2 + b_2 \, D_2 + b_3 \, D_3 \frac{\partial Y}{\partial X_2} - \lambda \frac{\partial Y}{\partial X_2} = 0 \tag{4.B.6}$$

$$\frac{\partial L}{\partial D_1} = b_1 X_1 - \mu \frac{\partial D_3}{\partial D_1} = 0 \tag{4.B.7}$$

$$\frac{\partial L}{\partial D_2} = b_2 X_2 - \mu \frac{\partial D_3}{\partial D_2} = 0 \tag{4.B.8}$$

$$\frac{\partial L}{\partial D_3} = b_3 Y - \mu = 0 \tag{4.B.9}$$

$$\frac{\partial L}{\partial \lambda} = Y^o - Y(X_1, X_2 X_3, \ldots, X_n) = 0 \tag{4.B.10}$$

$$\frac{\partial L}{\partial \mu} = D_3 - D_3 (D_1, D_2) = 0 \tag{4.B.11}$$

The first-order conditions regarding physical inputs can be derived from Equations 4.B.5 and 4.B.6, yielding the optimal factor-factor combination to produce and market a specified quantity of output. Substituting 4.B.9 into 4.B.7 and 4.B.8 we derive the necessary conditions for transfer-cost minimization plant location inside the triangle (not at a vertex):

$$b_1 X_1 = b_3 Y \left.\frac{\partial D_3}{\partial D_1}\right| D_2 \tag{4.B.12}$$

$$b_2 X_2 = b_3 Y \left.\frac{\partial D_3}{\partial D_2}\right| D_1 \tag{4.B.13}$$

Interpretation: at the point of minimum transport cost, the marginal rate of substitution between any two transport inputs (the other held constant) must equal the reciprocal of the ratio of their prices or the corresponding transportation rates [Isard, 1956, p. 224]. The possibility is recognized that one of the vertices may be the solution. The locational force toward (say) M could be sufficient to offset the combined forces pulling away. If a vertex is the solution the plant location transfer-cost minimization conditions are the same as 4.B.12 and 4.B.13 except "greater than or equal to" (≥) replaces equal (=). The over-all problem of plant location can be viewed as finding the equilibrium of locational pulls at each production point and market.

A graphical analysis has been worked out illustrating the simultaneous solution of optimal factor combination and optimal location [Moses, 1958]. The analysis explicitly assumes a production function homogeneous of the first degree.

Similar optimality conditions have been developed elsewhere [Lefeber, 1958, ch. 4]. Lefeber's primary purpose, in subsequent analysis, was to relax the continuity assumptions of Isard and formulate the problem in a programming framework. Paul Samuelson's now famous article opened the programming approach to spatial problems [Samuelson, 1952]. It also drew location analysis into closer contact with analogies to international trade analysis results. The activity analysis approach is much less restrictive than differential calculus. Hence, the following advantages: discontinuities can be handled, inequality relationships can be handled and the technique is less vulnerable to problems of myopia (global vs. local optimization).

Linear programming has been the context for solving many transportation problems. It is a special case having economic applications and computational simplicity. The formulation and computational procedures have been discussed in numerous references [Heady and Candler, 1964, ch. 10; Dorfman, Samuelson and Solow, 1958, ch. 5; and

Snodgrass and French, 1957]. The basic formulation is illustrated below.

$$
\begin{aligned}
&\text{MIN} && T = \Sigma_j\, \Sigma_i\, c_{ij}\, x_{ij} \\
&\text{subject to} && \Sigma_i\, x_{ij} = x_{\cdot j} \\
&\text{subject to} && \Sigma_j\, x_{ij} = x_{i\cdot} \\
&\text{subject to} && x_{ij} \geq 0
\end{aligned}
\qquad (4.B.14)
$$

where $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$

$x_{\cdot j}$ is quantity demanded at j-th location (known)

$x_{i\cdot}$ is quantity available at i-th location (known)

c_{ij} is cost of transporting one unit from i to j (known)

x_{ij} is quantity to be shipped from i to j (unknown)

The problem is to solve for the value of each x_{ij}. In setting up the solution procedure, the coefficient of each x_{ij} is either zero or unity, so a triangular submatrix (recursive system) is set up for each constraint set excepting nonnegativity of x_{ij}. Equalities hold if all demands and supplies are to enter the transportation system; no slack variables are needed. The computational ease results from the existence of equalities and recursiveness within the system.

The problem dimension can be expanded by including such other activities as processing. The transportation model can be applied at state, regional or national levels of aggregation. Or it may be applied at the firm level. It is important to note that cost minimization for each of several firms in an industry does not insure that transportation costs are minimized for the industry as a whole [Beckmann and Marschak, 1955, p. 136].

The time dimension context of linear programming and its related transportation model is short run. In the transportation problem both demand and supply nodes are taken as given. The capacity of altering the number of either is not available. This is the point of departure for the model applied in the present study. An attempt is made to achieve a long-run context by permitting the number, as well as locations and sizes, to vary.

V. A LONG-RUN SPATIAL MODEL

A. Analytical Framework

A theoretical construct having space as one component is a spatial model. These models are used in an attempt to provide information and related forecasts on: efficient shipping patterns, efficient regional production and resource allocation and effects of changes in exogenous variables [Bawden, 1964]. Spatial models may be classified into two groups: standard equilibrium models using demand and supply relations, and activity analysis formulations involving physical production activities and demand relationships. The principal distinction lies in treatment of the productive process -- the former models rely on explicit supply functions whereas the latter implicitly generate their own supply relationships [Bawden, 1964]. Research using spatial models should provide results useful for policy makers, consumers and the voting public and individual entrepreneurs.

Models can also be classified in the time dimension. Short-run models analyze with capital facilities taken as given. In a long-run context, the number of plants, their sizes and their locations can be allowed to vary. Such a model would have investment implications. That is, the supply relationships are generated within the model. The long-run spatial model described presently attempts to solve for plant numbers and sizes as well as locations. The objective is cost minimization; under perfect competition, cost minimization relates to profit maximization.

The feed manufacturing operation might be divided into 12 activity stages. In the following analysis these stages are assumed to be sufficiently independent to permit an additivity relationship in the calculation of total costs. A long-run analysis is assumed. Consider the following cost function expression:

$$\frac{1}{V}(TOTC) = \frac{1}{V}(\overline{TINGMC} + \overline{TINGTC} + \overline{TRD} + TINGBC + TINGHC + TINGPC + TMIXC + TPELC + TPKGC + TWHC + TDISTC + TSELLC) \qquad (5.A.1)$$

where V = volume

TOTC = total cost

TINGMC = total ingredient materials cost (fob)[1]

TINGTC = total ingredient transportation cost

TINGBC = total ingredient buying cost

TRD = total research and development costs

TINGHC = total plant receiving cost

TINGPC = total plant processing cost

TMIXC = total plant mixing cost

TPELC = total plant pelleting cost

TPKGC = total plant packaging cost

TWHC = total plant warehousing cost

TDISTC = total product transportation cost

TSELLC = total product selling cost

---

[1]Prices at the transportation facility at the geographic location from which the ingredient originates.

Dividing each term in 5.A.1 by V gives long-run average cost. Equation 5.A.1 can be rewritten as

$$\begin{aligned} AOTC = {} & \overline{AINGMC} + \overline{AINGTC} + \overline{ARD} + AINGBC + AINGHC \\ & + AINGPC + AMIXC + APELC + APKGC + AWHC \\ & + ADISTC + ASELLC. \end{aligned} \tag{5.A.2}$$

The bar (——) over three of the expressions denotes a constancy of average cost assumption with respect to both volume and distance which the final product must be transported; thus

$$\frac{d(AINGMC)}{dV} = \frac{d(AINGTC)}{dV} = \frac{d(ARD)}{dV} = 0$$

and (5.A.3)

$$\frac{d(AINGMC)}{d(DISTANCE)} = \frac{d(AINGTC)}{d(DISTANCE)} = \frac{d(ARD)}{d(DISTANCE)} = 0$$

The present study seeks the minimum cost locational pattern for the Iowa feed industry to supply its demand. Since the first three terms will not vary with respect to plant numbers, the three cost sources can be visualized as effecting merely an extension of the dependent axis when plant numbers are plotted against costs. In summary, the assumption is that per weight unit ingredient costs and average research and development costs are the same for any major population center in Iowa.

The last two terms in 5.A.1 will vary according to distances from market. Their cost magnitudes therefore vary with the number of plants.

The remaining seven terms represent components of feed manufacturing *per se*. They are: ingredient procurement, ingredient receiving, processing, mixing, pelleting, packing and warehousing. These are aggregated into what will be known as "plant manufacturing costs." It is assumed that problems of plant harmony have been resolved and that efficient production techniques are being utilized. This assumption is made reasonable by utilizing industry cost standards in synthesizing manufacturing costs by economic-engineering methods.

The total cost function can now be written more simply as

$$\text{TOTC} = \text{TPROCC} + \text{TDISTC} + \text{TSELLC} \tag{5.A.4}$$

where each term is affected by the number of plants.

The general model used to determine the optimum number, size and location of plants was developed at the University of California [Stollsteimer, 1963]. The problem is to determine simultaneously number, size and location of plants that minimize the total combined manufacturing, distribution and selling costs. Given a fixed volume of output, the model requires relationship expressions between number of plants and: manufacturing costs, distribution costs and selling costs. In addition, a relationship between manufacturing costs and output volume is needed.

Algebraically, the model is as follows:

$$\begin{aligned} \underset{(J,L_k)}{\text{MIN}} \quad \text{TC} &= \sum_{j=1}^{J} P_j F_j \Big|_{L_J} + \sum_{i=1}^{I} \sum_{j=1}^{J} F_{ij} T_{ij} \Big|_{L_J} \\ &\quad + \sum_{i=1}^{I} \sum_{j=1}^{J} F_{ij} S_{ij} \Big|_{L_J} \end{aligned} \tag{5.A.5}$$

with respect to plant numbers ($J \leq L$) and locational pattern $L_k = 1, 2, \ldots, {}_L C_J$, subject to

$$\Sigma_{i=1}^{I} \Sigma_{j=1}^{J} F_{ij} = F$$

$$\Sigma_{i=1}^{I} F_{ij} = F_j$$

$$\Sigma_{j=1}^{J} F_{ij} = F_i$$

$$F_{ij} \geq 0,\ T_{ij} \geq 0,\ S_{ij} \geq 0$$

where $i = 1, \ldots, I$ and $j = 1, \ldots, J$. A verbal description may be helpful. Given I demand nodes (F_i) to be supplied from any one or more of L possible locations. The problem is one of cost minimization determination. Total feed demand, for example, is to be manufactured, sold and transported as inexpensively as possible. The elements of the model are defined as follows:

TC = total combined manufacturing, selling and distributing cost

F = total quantity of product demanded

F_i = product demanded at demand node i

F_j = product supplied by supply node j

P_j = unit plant cost at supply node j

T_{ij} = unit cost of transport the product from j to i

S_{ij} = unit cost of selling to demand node i from supply node j

L_J = all combinations of locations for J plants

L_j = location of plant j

L_k = one combination of locations for J plants among the ${}_LC_J$ possible combinations of locations for J plants

The long-run spatial model described originally was developed as an assembly model. It has been developed in the present study as a distribution or disassembly model. The most complete use of the model's capability would be to use it for both assembly of input materials and distribution of final product.

B. Operational Solution Procedure

The total manufacturing cost function is

$$\underset{(J,L_k)}{TMC} = \Sigma_{j=1}^{J} P_j F_j \Big| L_J. \tag{5.B.1}$$

Since unit costs for both transportation and selling vary with distance from market, for computational purposes the latter two terms of 5.A.5 can be combined. Where $D_{ij} = T_{ij} + S_{ij}$, the total distribution cost function becomes

$$\underset{(J,L_k)}{TDC} = \Sigma_{i=1}^{I} \Sigma_{j=1}^{J} D_{ij} F_{ij} \Big| L_J \tag{5.B.2}$$

The total combined cost function including manufacturing, selling and distributing can be reduced from 5.A.5 to

$$\begin{aligned} \underset{(J,L_k)}{TC} &= \underset{(J,L_k)}{TMC} + \underset{(J,L_k)}{TDC} \\ &= \Sigma_{j=1}^{J} P_j F_j \Big| L_J + \Sigma_{i=1}^{I} \Sigma_{j=1}^{J} D_{ij} F_{ij} \Big| L_J \end{aligned} \tag{5.B.3}$$

Certain assumptions concerning the manufacturing cost function must be clarified. It is assumed that these costs are independent of plant location and that manufacturing technology remains unchanged during the period of model application.

Most plant cost empirical studies indicate that the total long-run cost-volume functional relationship is linear with a positive intercept.

This configuration implies economies of scale (declining L-shaped average cost function) and constant long-run marginal costs. The empirical results of the present study confirm the above description. Such a long-run manufacturing total cost function is depicted in Figure 5. The relation of total manufacturing cost to number of plants is illustrated in Figure 6. Total manufacturing costs will increase with the number of plants. With constant marginal processing costs and a positive intercept in the plant-cost function, total cost of processing a fixed quantity of material will increase by the amount of the intercept with each increase in plant numbers. Each additional plant will increase the total cost by the minimum annual cost of establishing and maintaining a plant.

There are I demand nodes to be served from J or fewer of J possible plant locations or supply nodes. The first step in minimizing the combined total cost function with respect to plant number (J) and plant location pattern (L_k) is to obtain a distribution cost function which has been minimized. The procedure is to assign plant numbers $j = 1, \ldots, J$ and compute the cost for each possible combination of each assigned number of plants. There are ${}_LC_J$ possible combinations of locations L_k/J. As an example, if there are eight potential plant sites, five plants can be arranged in $\frac{8!}{5!3!} = 56$ ways.

There is a (I by J) cost (C) matrix wherein each element represents transportation plus selling costs of each demand node i being supplied by each potential supply node j (plant location). If there are 99 counties and 50 potential plant sites, the C matrix is 99 by 50.

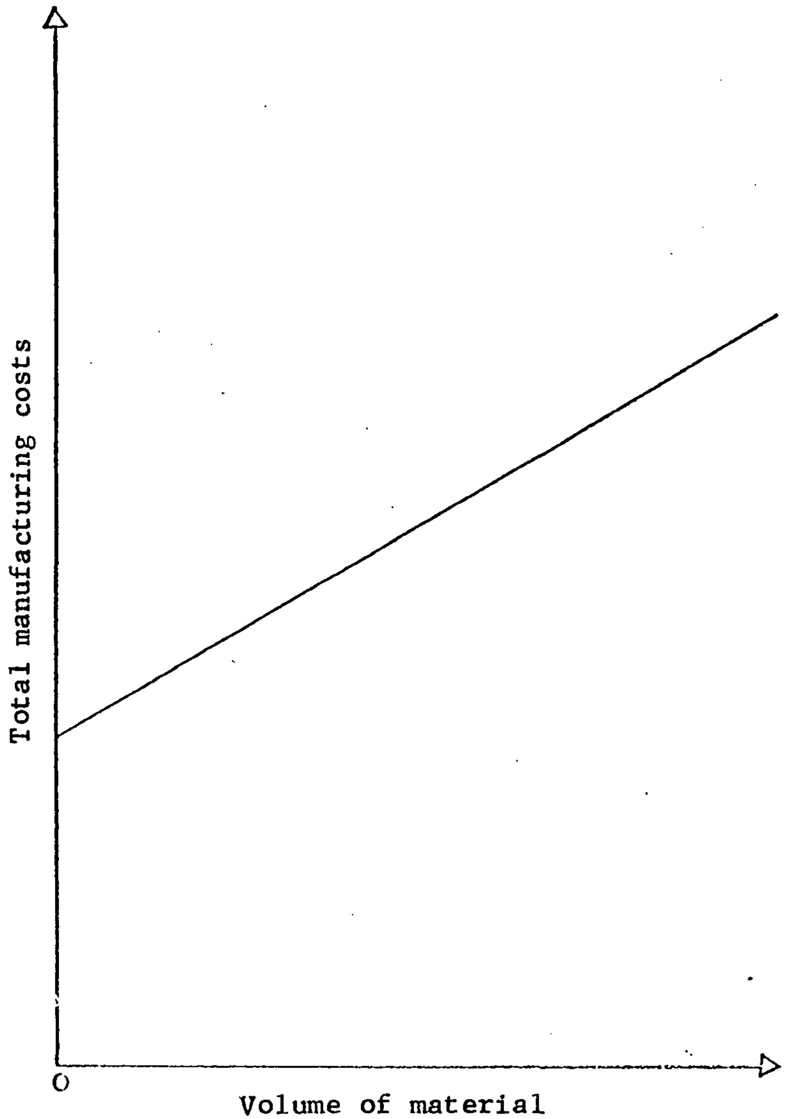

Figure 5. Total long-run manufacturing cost function for a single plant

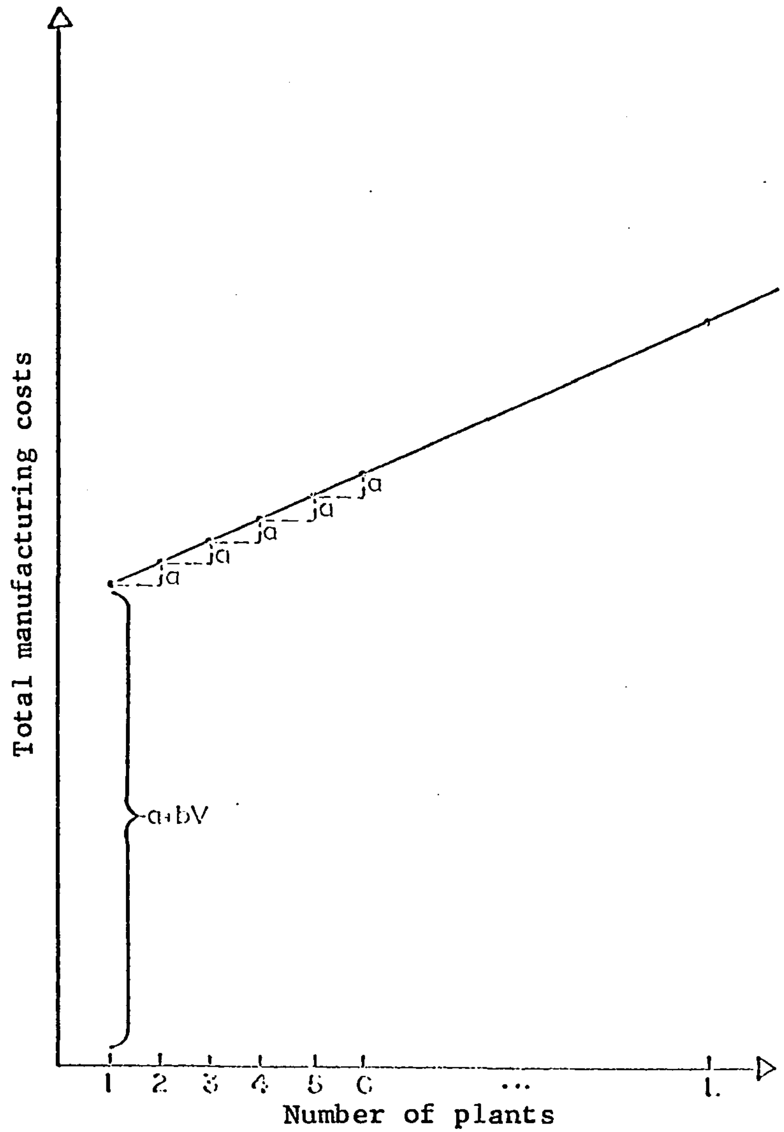

Figure 6. Total manufacturing cost curve

For each possible locational pattern, L_k, there is a submatrix C_{ij}^{*}/L_k of matrix C. The dimensions of this submatrix are (I by j) where j is the assigned number of plants. A vector C_{ij}^{min}/L_k is obtained by scanning C_{ij}^{*}/L_k by rows and selecting the minimum C_{ij} in each. Minimum total distribution costs, with j plants and a fixed locational pattern L_k, are equal to the conformable product of the C_{ij}^{min}/L_k vector and the vector of quantities demanded at each demand node i. The resultant expression is

$$(F_i^{\,o}) \quad C_{ij}^{min}/L_k$$

where $F_i^{\,o}$ is the vector of fixed quantities demanded.

There are ${}_LC_J$ such values for each value of j. The minimum of these values over L_k is a point on the distribution cost function minimized with respect to plant locations. The result is j values of the function

$$TDC^{min} = L_k^{min} \; (F_i^{\,o}) \; C_{ij}^{min}/L_k \tag{5.B.4}$$

where

TDC^{min} = total distribution cost minimized with respect to plant location for each $j = 1, 2, \ldots, J$

The nature of this function is depicted in Figure 7. The shape of the TDC^{min} function is deduced from the expected signs of the first and second differences with respect to varying plant numbers [Stollsteimer, 1963]. It is to be expected that both transportation and selling costs will be reduced with the addition of more plants; hence,

$$\frac{\Delta TDC^{min}}{\Delta J} \leq 0. \tag{5.B.5}$$

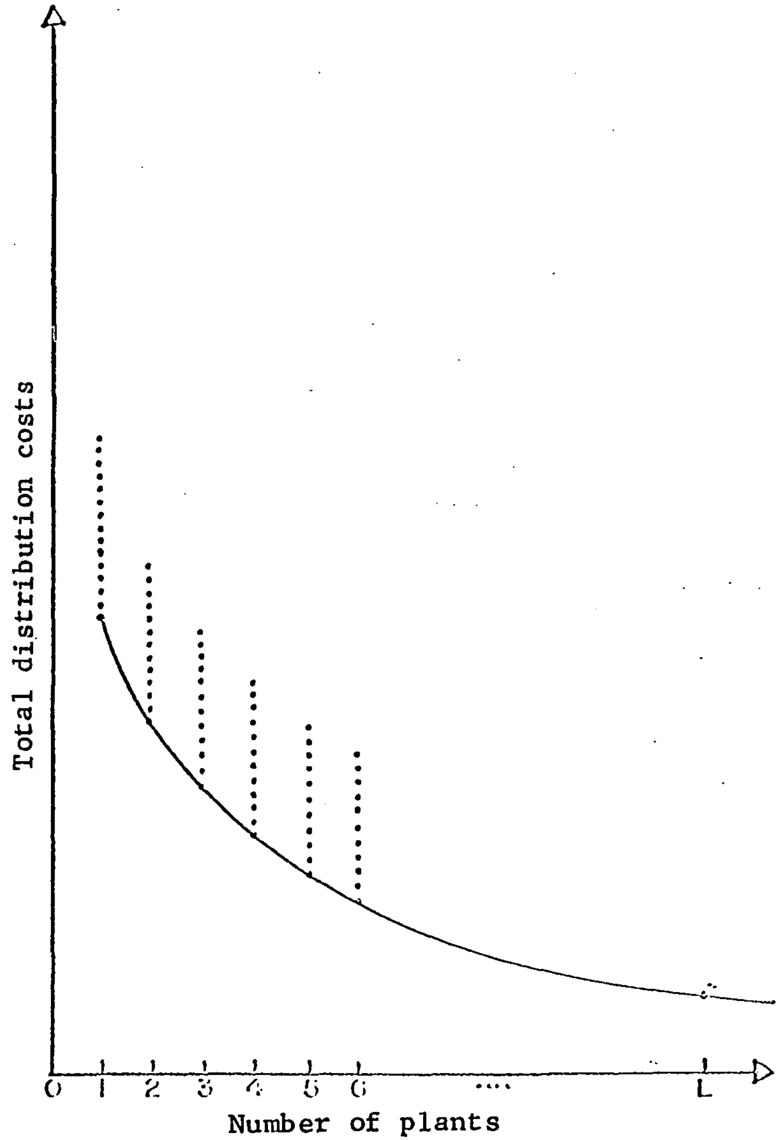

Figure 7. Minimized total distribution cost function

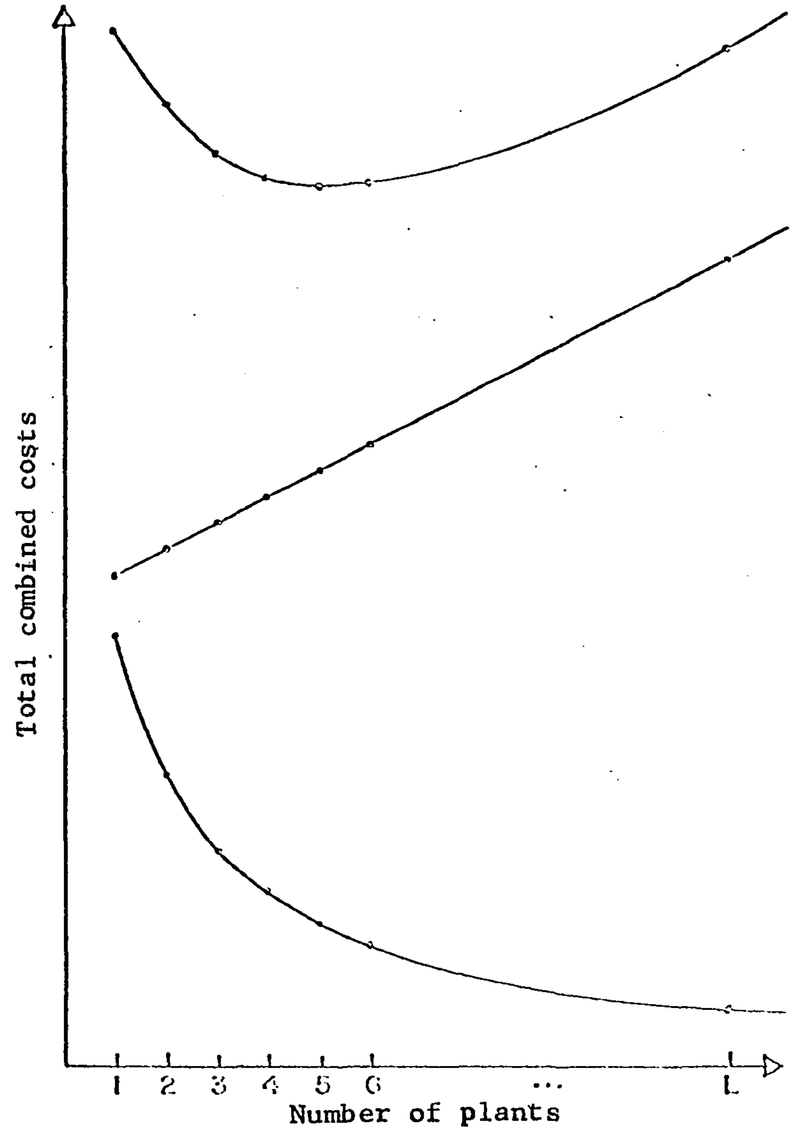

Figure 8. Total combined cost function, total manufacturing cost function and minimized total distribution cost function

The first difference will be less than zero as long as there exists an element C_{ij}^{**} in C but not in C_{ij}^{min}/L_k such that $C_{ij}^{**} < C_{ij}^{min}$ for some i. The sign of the second difference is less certain but is expected to be positive or zero; hence,

$$\frac{\Delta^2 TDC^{min}}{\Delta J^2} \geq 0. \qquad (5.B.6)$$

In brief, a decreasing monotonic convex (to the origin) function is expected. It has been shown that it is possible to construct numerical situations in which the second difference is negative [Hoch, 1965]. However, Hoch notes that if one vector (only) enters, the second difference cannot be negative; barring special constructions the non-negativity expectation holds.

After the minimized distribution function has been obtained, the second major computational step is to add manufacturing costs. The total combined cost function

$$\underset{(J)}{TC} = \underset{(J)}{TMC} + \underset{(J)}{TDC^{min}} \qquad (5.B.7)$$

is obtained. Recall that the distribution cost function (TDC) has been minimized with respect to locational pattern, L_k, for each number of plants J. Figure 8 illustrates that the total combined is the vertical summation of the manufacturing and minimized distribution cost functions. The minimum point on the total combined cost solves for the optimum number of plants. The distribution cost function minimization procedure determined which L_k (locational pattern) of the ${}_LC_J$ possible combinations was optimal for each number of plants.

Thus the location of each of the optimum number of plants is determined. The size of each plant is deduced from the magnitude of demand to be served.

The foregoing computational procedure is to compute every conceivable cost situation choosing plant numbers, sizes and locations to minimize cost. However, if all conceivable calculations must be made, the model's usefulness is severely restricted because of application cost. The relation of computations to number of plants considered is roughly exponential. The computational cost burden soon becomes astronomical. For example, computer science people estimated that taking all combinations of 50 plants would be about one year of work for the computer. Unless the bulk of the computations are circumvented, the model's use is limited to only small problems.

The validity of one assumption is crucial. If an assumption of convexity holds for the total combined cost function, the computational cost burden can be relieved immensely. In a convex set any local optimum is also a global optimum. Suppose there are 50 potential plant sites. Suppose calculations are made for one plant, five plants and ten plants -- if cost (1) > cost (5) > cost (10), the calculations for two, three and four plants need not be made. If cost (15) > cost (10), the optimum number must lie between five and 15 plants, and if cost (15) > cost (5), the optimum probably lies between five and ten plants (this conjecture is confirmed if cost (8), for instance, is less than cost (10)). If cost (9) > cost (8) and cost (7) > cost (8), then eight is the optimum number of plants.

In this hypothetical example, calculations are needed for only seven different plant numbers -- a small fraction of the total conceivable calculations.

Only a few studies have used this long-run spatial model. Aside from Stollsteimer's study of pear assembly and processing, the model has been used in Iowa to study egg marketing organization [Sanders and Fletcher, 1966] and in North Carolina to locate egg grading and packing plants [Peeler and King, 1964]. A Louisiana study generalized the model to permit multiple product processing of vegetables [Polopolus, 1965]. In each of these studies only a few potential plant locations were considered. The present study is perhaps the first to explore use of this long-run spatial model for a problem with large dimensions. An incidental but important contribution of the present study is methodology to minimize the model's computational burden. This should allow wider application.

C. Example Problem

The computational details of minimizing the distribution cost function are fairly complex. Consequently a simple example is worked out to help clarify the procedure. Suppose there are eight demand nodes and five potential plant locations or supply nodes. For each possible plant number, what is the cost-minimizing location pattern? The procedure will be illustrated using the following (5 by 8) matrix of hypothetical data. The matrix can be thought of as representing either total cost of selling and transporting to each demand node from each supply node, or, the per unit distributing cost to be multiplied by a unit demand quantity vector.

		Demand nodes							
		D1	D2	D3	D4	D5	D6	D7	D8
Potential plant locations	L1	7	6	9	0	3	1	4	6
	L2	6	1	5	8	4	9	5	5
	L3	2	3	8	9	7	4	8	1
	L4	4	7	3	2	6	0	7	8
	L5	9	5	7	1	2	5	6	4

Figure 9. Hypothetical cost matrix

For one plant, each row vector is summed, giving the respective sums of 36, 43, 42, 37 and 39. If one plant were to be located, costs would be minimized by locating at L1 where cost = 36. For two plants there are ${}_5C_2 = 10$ possible location combinations. Since it turns out that the least-cost pair is L1 and L3, the detailed procedure will be illustrated for this pair. Call the matrix H so the elements are h_{ij}. Consider rows L1 and L3: $h_{31} < h_{11}$ $(2 < 7)$, $h_{32} < h_{12}$ $(3 < 6)$, $h_{33} < h_{13}$ $(8 < 9)$, $h_{14} < h_{34}$ $(0 < 9)$, $h_{15} < h_{35}$ $(3 < 7)$, $h_{16} < h_{36}$ $(1 < 4)$, $h_{17} < h_{37}$ $(4 < 8)$ and $h_{38} < h_{18}$ $(1 < 6)$. The minimized cost vector, C_{ij}^{min}/L_k in previous notation, is 2, 3, 8, 0, 3, 1, 4, 1 and its sum is 22. If two plants were to be located, they should be located at L1 and L3. L1 would serve demand nodes D4, D5, D6 and D7; meanwhile, L3 would serve D1, D2, D3 and D8.

For three plants there are ${}_5C_3 = 10$ possible location patterns. The same procedure is followed with the solution that a combination of L1, L3 and L4 is least cost. The cost figure is 16. While L1 serves D4, D5 and D7, L3 serves D1, D2 and D8, and L4 serves D3 and D6. For four plants the least cost of five possible combinations is L1, L2, L3 and L4. The cost total is 14. Of course, all five plants can be located but one way. The cost is reduced to 13.

Notice that the model's first and second difference expectations hold. The first differences are: -14, -6, -2 and -1. The second differences are: +8, +4 and +1. The expectations that

$$\frac{\Delta TDC^{min}}{\Delta J} \leq 0$$

and

$$\frac{\Delta^2 TDC^{min}}{\Delta J^2} \geq 0$$

are confirmed in this example. These results can be interpreted as follows: as plant number increases, minimized distribution costs decrease at a decreasing rate.

D. Data Requirements of Model Use in the Present Study

The data requirements for using the long-run spatial model are substantial. These requirements will be outlined briefly. The subsequent chapter will detail the data sources, procedures and results of preparing data for submission into the model.

Feed demand estimates are basic to the model. Each of Iowa's 99 counties was considered to be a demand node. Demand estimates were based on livestock numbers from the 1964 Census of Agriculture. USDA data, procedures and coefficients were used to get basic total concentrates estimates. Then Iowa Department of Agriculture data and information on recommended rations were used to obtain estimates of complete feed and supplement tonnages for each of 16 livestock classes in each county. A final result was a combined tonnage estimate for each county. The value of the long-run spatial model is to answer the following questions: From which supply nodes should these demand magnitudes be met and what will be the cost?

Transportation cost is an important variable in determining an optimal location pattern. Three steps were necessary: define a set of potential plant sites (supply nodes), develop a transportation matrix relating demand and supply nodes and ascertain per mile costs for transporting feeds. Only centers of 5,000 or more population were allowed as potential plant sites. There are 51 of these in Iowa. A transportation matrix, dimensioned 51 by 99, was developed. The procedure and results are detailed in a separate paper now in the publication process.

For-hire truckers are required to file tariffs with the Iowa Commerce Commission. A survey of this information was supplemented by an Iowa State University survey to obtain costs for transporting feeds. It became possible to estimate the transportation cost of supplying each demand node from each potential supply node.

Selling costs vary with distance and therefore affect the optimal location pattern. Selling cost information was obtained from a USDA publication. Combining cost information with the transportation matrix facilitated an estimation of selling costs for supplying each demand node from each potential supply node. The term "distribution" costs will refer to transportation plus selling costs.

The final basic data requirement of the long-run spatial model is cost of manufacturing commercial mixed feeds. The manufacturing cost data developed in the present study represent a synthesis of cost information from several published studies. A long-run average cost-volume relationship is developed for both single- and double-shift operations. Several adjustments had to be made in order to make the cost results applicable to the Iowa situation. The manufacturing cost results have a normative connotation. The bases for costs are industry standards for the various manufacturing functions; according to the feed manufacturing associations, the standards are attainable by the elements of the industry.

VI. DEVELOPMENT OF DATA REQUIREMENTS

A. Spatial Delineation of the Study

The spatial region considered in this study is the state of Iowa. The basis of this consideration is substate -- each of the 99 counties. The marketing dimension scope is feed manufacturing and distribution to the wholesale level; that is, to retail outlets and/or large-volume consumers. Retail distribution has received attention in other studies. In Iowa, counties are numbered lexicographically and are referred to in this manner by both state agencies and the Census Bureau.

One reference point was chosen for each county. In general, the reference point was the geographic center. Since most counties are rectangular in configuration, the geographic center could be determined as the intersection of two corner-to-corner lines traversing the county diagonally. In some cases the reference point was adjusted slightly from the geographic center. It seemed realistic, from a point of view of transporting people or materials, to allow the reference point to be a trade center, major road intersection or point on a major road if only a small adjustment was required. A small adjustment was defined as being 3 miles or less. This minor adjustment is justified by the consideration that towns and roads have been established to facilitate the needs of people and their economic (and other) activity. A transportation network should serve commerce and people rather than mere geography.

Implicit in the procedure of choosing one reference point in each county is the idea that the reference point represents the average number of miles traveled into the county from any given potential manufacturing plant location distributing to that county. Suppose a manufacturing plant is located in Mason City and the distribution to Hamilton County is considered. If product distribution is to be to (say) eight random points in the county, the average distance to these points can be approximated by the distance to the geographic center of the county.

Major population centers, defined as those centers whose 1960 Census populations exceeded 5,000, were regarded as potential plant locations. Such a definition is arbitrary. In choosing potential plant sites, it was felt that centers with 5,000 or more persons could offer minimum facilities and environment that would be attractive to a company (or cooperative) contemplating the establishment of a manufacturing plant. By facilities it is meant to consider a manufacturing plant's need for water, electricity, financial institutions, communications and transportation channels. The facilities already present in the previously defined major population centers can likely support an additional plant of at least moderate size. The local labor market is an additional concern. It would be desirable for a plant to be located where the labor pool is so large as to preclude any serious distortion of the local labor market as needed personnel are hired. The term environment considers community living aspects such as available housing, school, church and recreation facilities. It was felt that adequate provision of such factors would exist for any center of 5,000 or more persons.

The accompanying list of centers (Table 5) met the 5,000 population minimum. When two centers within 10 miles of each other met the

Table 5. List of selected potential plant sites in Iowa, their 1960 populations and county location

	Center	Population	County	County No.
		('000)		
1.	Algona	5.7	Kossuth	55
2.	Ames	27.0	Story	85
3.	Atlantic	6.9	Cass	15
4.	Boone	12.5	Boone	8
5.	Burlington	35.0	Des Moines	29
6.	Carroll	7.7	Carroll	14
7.	Cedar Rapids	102.9	Linn	57
8.	Centerville	6.6	Appanoose	4
9.	Chariton	5.0	Lucas	59
10.	Charles City	10.0	Floyd	34
11.	Cherokee	7.7	Cherokee	18
12.	Clarinda	5.9	Page	73
13.	Clinton	33.6	Clinton	23
14.	Council Bluffs	55.6	Pottawattamie	78
15.	Creston	7.7	Union	88
16.	Davenport	100.5	Scott	82
17.	Decorah	6.4	Winneshiek	96
18.	Des Moines	226.7	Polk	77
19.	Dubuque	55.6	Dubuque	31
20.	Estherville	7.9	Emmett	32
21.	Fairfield	8.1	Jefferson	51
22.	Fort Dodge	28.4	Webster	94
23.	Fort Madison	15.2	Lee	56
24.	Grinnell	7.4	Poweshiek	79
25.	Independence	5.5	Buchanan	10
26.	Indianola	7.1	Warren	91
27.	Iowa City	35.8	Johnson	52

Table 5. (Continued)

Center		Population	County	County No.
		('000)		
28.	Iowa Falls	5.6	Hardin	42
29.	Keokuk	16.3	Lee	56
30.	Knoxville	7.8	Marion	63
31.	LeMars	6.8	Plymouth	75
32.	Maquoketa	5.9	Jackson	49
33.	Marshalltown	22.5	Marshall	64
34.	Mason City	30.6	Cerro Gordo	17
35.	Mount Pleasant	7.3	Henry	44
36.	Muscatine	21.0	Muscatine	70
37.	Newton	15.4	Jasper	50
38.	Pella	5.2	Marion	63
39.	Perry	6.4	Dallas	25
40.	Oelwein	8.3	Fayette	33
41.	Oskaloosa	11.1	Mahaska	62
42.	Ottumwa	33.9	Wapello	90
43.	Red Oak	6.4	Montgomery	69
44.	Shenandoah	6.6	Page	73
45.	Sioux City	89.2	Woodbury	97
46.	Spencer	8.9	Clay	21
47.	Storm Lake	7.7	Buena Vista	11
48.	Washington	6.0	Washington	92
49.	Waterloo	98.7	Black Hawk	7
50.	Waverly	6.4	Bremer	9
51.	Webster City	8.5	Hamilton	40

specification, they were regarded as one; these cases were Des Moines-West Des Moines-Urbandale, Mason City-Clear Lake, Davenport-Bettendorf, Waterloo-Cedar Falls-Evansdale and Cedar Rapids-Marion. A total of 51 potential plant sites were selected using the 5,000-population criteria. Their geographic dispersion is illustrated in Figure 10. It can be observed that these centers are well dispersed. If one were to draw circles around each center, using a 50-mile radius, it would be discovered that the entire state is contained with the exception of a very small corner of Lyon County.

B. Demand Analysis

1. Explanation of census data

Census of Agriculture data are useful in accomplishing the objectives of this report for a number of reasons. The census is recognized generally as the researchers' most complete and accurate data source -- in fact, most other data sources use census data as a benchmark for periodic revisions. Fortunately, the recent release of 1964 census data makes the data contained therein highly current. Moreover, the census is one of the few systematic data sources which is disaggregated to the county level. Frequently research, extension and policy-making objectives are difficult to fulfill without county level data.

The 1964 Census of Agriculture is, thus far, a preliminary report [Census of Agriculture, 1965]. There may be some minor revisions. The data for 1964 were gathered in the fall (November-December) of that year and are comparable to final data for 1959 [Census of Agriculture, 1960]. The source of data was farm operators. They were

Figure 10. Geographic dispersion of 51 Iowa centers with 5,000 or more population

mailed questionnaires in advance and then visited by a census enumerator. Some data are based on enumeration of each farmer and some are estimates based on a sample of approximately one-fourth.

Data used in this report refer to "on farms" or "sold from farms"; therefore, the census definition of a farm is of importance. Farms are defined as follows: "Census farms comprise places on which agricultural operations were conducted at any time under the control or supervision of one person, a partnership or a manager. Places of less than 10 acres were counted as farms if the estimated sales of agricultural products for the year amounted, or normally would amount, to at least $250. Places of 10 or more acres were counted as farms if the estimated sales of agricultural products for the year amounted, or normally would amount, to at least $50" [Census of Agriculture, 1965]. Some livestock would be produced in situations not within the definitional boundaries. The magnitude of omission was regarded as inconsequential and thus ignored.

Data for livestock inventory relate to date of enumeration. However, data for sales of livestock and livestock products (and their corresponding dollar value) are for the calendar year. These statements hold for both the 1959 and 1964 censuses.

Following a procedure developed by the USDA, animal unit calculations were made for Iowa. The procedure for county animal unit calculations is precisely analogous to that for state totals. Inasmuch as the livestock classes breakdown differs between the Census of Agriculture and USDA data, certain reconciliations had to be achieved.

In addition, the present study procedure was applied at the county level while USDA calculations are done at the state level. As an empirical check on present study procedures, it was crucial that present study animal unit totals for Iowa relate closely to USDA totals. The long-run spatial model will be applied to 1964 data. However, the present study's animal unit derivation procedure is applied to both 1959 and 1964 Census of Agriculture data. Greater confidence can be held for the procedure if results correspond closely to both 1959 and 1964 USDA totals.

2. Derivation of standard animal units

The present study seeks to determine an efficient location pattern for feed manufacturing plants in Iowa. A worthy objective, from the points of view of either individual companies or public welfare, is that plants serve the feed demand by manufacturing and distributing the feed as inexpensively as possible. Development of county-level demand data is requisite to addressing the problem of how to most efficiently supply the feed requirements of each county.

The United States Department of Agriculture (USDA) has developed a procedure for converting livestock numbers into "standard animal units" [USDA Statistical Bulletin 324, 1963]. These animal units are a measure of livestock numbers weighted by feed consumption. Current feed consumption data are available for various classes of livestock [Hodges, 1964]. It is possible to estimate feed requirements from animal unit computations; feed per animal unit has been estimated in a time series.

Feed demand requirements, based on livestock numbers, can be estimated for local, state, regional or national levels and compared to available supplies at corresponding levels of geographic aggregation. Researchers in Iowa might focus their concern on local (county) and state (Iowa) levels.

An animal unit is defined as the equivalent of one milk cow in terms of feed consumed per year [USDA Statistical Bulletin 301, 1961]. Numbers of each kind of livestock, including poultry, are converted into animal units by weighting such numbers by a factor. The factor, for a particular class of livestock, is the ratio of the amount of feed consumed per head per year to that for one milk cow. That is,

$$f_1 = \text{factor} = \frac{\text{amt. of feed consumed} \;/\; 1 \;/\; \text{year}}{\text{amt. of feed consumed} \;/\; \text{milk cow} \;/\; \text{year}}$$

where 1 refers to the class of livestock. The base period for the computation of the factors is 1940-45 for all classes of livestock except broilers. It is 1950-53 for broilers.

Animal units are computed and presented by the USDA in three basic series:

i) concentrate-consuming animal units, or livestock and poultry weighted by consumption of concentrates[1],

ii) roughage-consuming animal units, or livestock numbers weighted by consumption of roughages including pasture and

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[1]The term concentrates includes feed grain, corn hogged-off, oilseed meals, animal proteins, grain proteins, millfeeds, added fats and miscellaneous low fiber feeds.

iii) concentrate- and roughage-consuming animal units, or livestock numbers weighted by all feed.

A subset of the concentrate series, called the high-protein-consuming animal units, is also computed. Current data and computations of all these series are published by the USDA, Economic Research Service, in statistical bulletin annual supplements.

Since the objectives of this paper are in terms of the demand for livestock feeds of commercial source (that is, manufactured feeds), consideration will henceforth refer only to the first of the three animal unit series. Concentrate-consuming animal units (grain-consuming in USDA parlance) will hereafter be implied by the term "animal units." The commercial mixed-feeds industry produces mainly concentrates -- supplements or complete feeds (supplements plus feed grain).

The USDA calculates animal units for the "feeding year" beginning October 1. Examples of national calculations of animal units can be found in USDA's FEED SITUATION from time to time. Their method of calculation becomes self-evident when the coefficients in Table 6 are interpreted properly. There is considerable state and regional variation in the factors for converting livestock numbers into animal units. In addition to national calculations, the USDA determines animal units for each state. The 1950-64 times series of animal units for the U.S. (48 states), the North Central region, the Corn Belt and Iowa is presented in Table 7. Various regional totals can be obtained by aggregating appropriate states.

Table 6. Factors for grain-consuming animal units, national[a] and Iowa, 1964[c]

		U.S.	Iowa
1.	Milk cows and heifers two years old and over	1.03	1.20
2.	Heifers and heifer calves kept for milk[b]	0.35	0.50
3.	Beef cows two years old and over	0.17	0.40
4.	Cattle on feed	1.95	2.50
5.	All other cattle[b]	0.16	0.30
6.	Stock sheep on farms	0.022	0.050
7.	Horses and mules two years old and over	1.31	1.40
8.	Colts	0.15	0.20
9.	Hogs fed during feeding year	0.72	0.75
10.	Hens and pullets on farms	0.06	0.055
11.	Chickens raised during the year	0.017	0.020
12.	Turkeys raised during year	0.07	0.07

[a]The base (1.00) for the factors in this table is the average quantity of grain and other concentrates consumed annually by the average milk cow in the U.S. during the period 1940-45. The factors for sheep and lambs on feed is 0.12 and for broilers is 0.0008; they are the same for all states.

[b]The factors for heifer and heifer calves kept for milk include an allowance for dairy bulls; "other cattle" includes an allowance for beef bulls.

[c]Sources: USDA Statistical Bulletin 337, 1964, p. 45; and USDA Statistical Bulletin 337 Supplement, 1965, p. 17.

Table 7. Concentrate-consuming animal units, U.S., N.C. region, Corn Belt and Iowa, 1950-1964[d]

	Year beginning October 1 (feeding year)*							
	1964[α]	1963	1962	1961	1960	1959	1958	1957
	(thousands)							
Iowa	23,710	24,449	24,500	23,868	23,658	23,940	24,709	22,755
Corn Belt[a]	59,067	62,271	63,041	61,542	61,306	61,401	63,437	59,954
N.C. region[b]	95,891	100,485	101,223	99,222	98,626	98,043	101,497	45,190
U.S.[c]	167,664	172,259	172,801	168,986	167,557	165,748	167,728	159,905

*Year of reference relates to October 1; e.g., 1963 here is October 1, 1963 to September 30, 1964.

[α]Preliminary.

[a]Corn Belt: Ohio, Indiana, Illinois, Iowa and Missouri.

[b]N.C.: (a) plus Michigan, Wisconsin, Minnesota, North Dakota, South Dakota, Nebraska and Kansas.

[c]48 states; data not available for (Alaska and Hawaii).

[d]Sources: USDA Statistical Bulletin 337, 1964; USDA Statistical Bulletin 337 Supplement, 1965; and USDA Statistical Bulletin 301, 1961.

Table 7. (Continued)

	Year beginning October 1 (feeding year)						
	1956	1955	1954	1953	1952	1951	1950
				(thousands)			
Iowa	22,674	23,663	23,784	22,359	23,027	23,446	n/a
Corn Belt[a]	61,101	62,946	61,245	58,740	59,630	62,307	n/a
N.C. region[b]	96,000	100,048	99,073	94,944	95,963	100,656	n/a
U.S.[c]	160,927	165,264	161,595	156,853	158,936	167,331	168,104

However, these USDA data are not disaggregated to any substate levels such as counties. County estimates are needed for the present study. The most reliable and complete county-level data source is the census.

This section presents animal units and the derived feed requirements for each Iowa county and the state total. The Census of Agriculture affords a basis for the substate animal unit calculations. The major hurdle is the problem of data comparability between the census and the data used by the USDA for animal unit calculations. It was useful to achieve data comparability of livestock classifications so that USDA conversion factors could be applied to the census data.

Four basic steps were followed in order to calculate animal units from Census of Agriculture data: i) careful notice and interpretation was given to USDA animal unit totals and the livestock classes entering the calculations; ii) livestock classes of the census precisely corresponding to USDA classifications were noted; iii) census data were adapted where necessary to achieve comparability with USDA data; and iv) animal unit totals for Iowa based on census data were compared with USDA results.

The USDA calculation procedure was analogized using adapted 1964 and 1959 Census of Agriculture data. This application to state of Iowa data is illustrated in Tables 8 and 9. The 1959 procedure is somewhat more complicated, involving more ratio estimates, than 1964 because several disaggregations available for 1964 were not available from 1959 data.

Table 8. Iowa calculation of animal units, 1964

Livestock class	Source of calculation[a]	Number of head	Conversion factor[a]	Animal units	Variable name
		('000)		('000)	
A. On farms at census					
1. Milk cows	Direct from 1964 census	735.6	1.2	882.8	M1COWS
2. Milk heifers and heifer calves	(212 + 233)/861 736	380.2	0.5	190.1	MH2HC
3. Beef cows	1983 - 736	1,247.1	0.4	498.8	B3COWS
4. Cattle on feed	(1731/7124)(7285)(3154/(3154+387)	1,590.2	2.5	3,975.6	FINV4L
5. Calves on feed	(1731/7124)(7285)(357/(3154+357)	179.9	1.8[a]	323.8	FINV5S
6. Other cattle	Residual from 7285	3,151.9	0.3	945.6	OTH6
7. Horses and mules	Direct from 1959 census	81.1	1.4	113.6	H7M
8. Stock sheep	(900/1312)(1365)	936.3	0.05	46.8	ST8SH
9. Sheep on feed	(412/1312)(1365)	428.6	0.12	51.4	FD9SH
10. Chickens over 4 months	Direct from 1964 census	19,503.6	0.055	1,072.7	C10OLD
11. Turkeys for breeding	Direct from 1964 census	199.5	0.07	14.0	T11BR
12. Swine for breeding	Direct from 1964 census	1,959.0	0.75	1,469.3	SW12BR
B. Sold during year					
13. Broilers	Direct from 1964 census	1,906.4	0.008	15.3	BR13
14. Other chickens for slaughter	Direct from 1964 census	12,822.4	0.02	256.4	OC14SL
15. Turkeys raised	Direct from 1964 census	8,297.2	0.07	580.8	TUR15R
16. Hogs sold	Direct from 1964 census	19,883.0	0.75	14,912.3	HOG16S
TOTAL				25,349.3	TOTAL

[a]See text for full explanation of these items.

Table 9. Iowa calculation of animal units, 1959

Livestock class	Source of calculation[a]	Number of head	Conversion factor[a]	Animal units	Variable name
		('000)		('000)	
A. On farms at census					
1. Milk cows	Direct from 1959 census	830.6	1.2	996.7	M1COWS
2. Milk heifers and heifer calves	(248 + 265)/1024)(831)	416.1	0.5	208.1	MH2HC
3. Beef cows	1792 - 831	961.6	0.4	384.6	B3COWS
4. Cattle on feed	(1425/6536)(6480)(3154/(3154+357)	1,269.2	2.5	3,173.0	FINV4L
5. Calves on feed	(1425/6536)(6480)(357/(3154+357)	143.6	1.8[a]	258.4	FINV5S
6. Other cattle	Residual from 6480	2,858.8	0.3	857.6	OTH6
7. Horses and mules	Direct from 1959 census	81.1	1.4	113.6	H7M
8. Stock sheep	(1132/1632)(1792)	1,242.9	0.05	62.1	ST8SH
9. Sheep on feed	(500/1632)(1792)	549.0	0.12	65.9	FD9SH
10. Chickens over 4 months	Direct from 1959 census	26,700.6	0.055	1,468.5	C10OLD
11. Turkeys for breeding	Direct from 1959 census	179.6	0.07	12.6	T11BR
12. Swine for breeding	(1959/13692)(14789)	2,116.0	0.75	1,587.0	SW12BR
B. Sold during year					
13. Broilers	(1906/19504)(26701)	2,609.8	0.008	20.9	BR13
14. Other chickens for slaughter	(12822/19504)(26701)	17,553.9	0.02	351.1	OC14SL
15. Turkeys raised	Direct from 1959 census	8,158.1	0.07	571.1	TUR15R
16. Hogs sold	Direct from 1959 census	18,589.8	0.75	13,942.4	HOG16S
TOTAL				24,073.6	TOTAL

[a]See text for full explanation of these items.

Following is a detailed entry-by-entry explanation of livestock number derivations, first for 1964 and then for 1959. The 1964 explanation is now detailed:

1) The milk cow figure is available directly from 1964 Census of Agriculture data;

2) the milk heifers and heifer calves figure is calculated assuming the ratio of this class to milk cows is the same for the 1964 census as the USDA figures for 1964 -- the USDA recorded 212 ($X10^3$) milk heifers and 233 ($X10^3$) milk heifer calves with 861 ($X10^3$) milk cows [USDA Statistical Bulletin 333 Supplement, 1965]. Standard ratio estimation techniques allow estimating the number of milk heifers and heifer calves in the 1964 census by (212 + 233) -- 861 times 736 where 736 ($X10^3$) is the number of milk cows recorded by the 1964 census;

3) the beef cow figure is obtained from the census simply by subtracting milk cows from "cows including heifers that have calved";

4 & 5) the figure for cattle and calves on feed in Iowa as of January 1, 1964 was recorded by the USDA along with a figure for total cattle and calves on farms as of that date [USDA Statistical Bulletin 333 Supplement, 1965] -- the ratio of "on feed" to "total" was assumed to apply to Iowa census data consequently allowing estimation of Iowa's cattle and calves on feed by (1731/7124)(7285) where 7285 ($X10^3$) is the census figure. In addition, it seemed desirable to

disaggregate to cattle on feed and calves on feed -- this was accomplished using 1964 census data for cattle sold that were "fattened on grain and concentrates" and calves similarly "finished" for market. The former figure is 3154 ($X10^3$) and the latter is 357 ($X10^3$), so the cattle and calves on feed, respectively, can be estimated using the ratios 3154/(3154 + 357) and 357/(3154+357) -- the composite procedure (at the state level) for 4) becomes (1731/7124)(7285)(3154/3511) and that for 5) becomes (1731/7124)(7285)(357/3511);

6) as recognized in the USDA animal unit calculations, there are many "other" cattle -- this figure is estimated as a residual of 7285($X10^3$) minus the sum of the preceding five classes where 7285 ($X10^3$) denotes total cattle and calves in Iowa as recorded by the 1964 Census of Agriculture;

7) the 1964 census did not record numbers of horses and mules, so the 1959 figure was used; and

8 & 9) the 1964 census data on total sheep and lambs were disaggregated on the basis of ratios derived from USDA data [USDA Statistical Bulletin 333 Supplement, 1965] -- the USDA ratio of stock sheep to total for Iowa is (900/1312) while (412/1312) refers to those on feed. Respectively expressed as proportions of Iowa's 1964 census total, the calculations become (900/1312)(1365) and (412/1312)(1365) where 1365 ($X10^3$) is the Iowa census total of sheep and lambs.

All of the remaining 1964 classes can be obtained directly from Census of Agriculture results; the livestock classes represented by these seven categories can be read off the illustrated Iowa animal unit calculation for 1964.

In the Iowa calculation of 1959 animal units, the basic procedure is analogous to the 1964 procedure. Some classes could be taken directly from the 1959 census data: 1), 7), 10), 11), 15) and 16). A procedure precisely analogous to 1964, except for using a different USDA data source [USDA Statistical Bulletin 230 Supplement, 1960], applies to several livestock categories: 2), 4), 5), 8) and 9). Procedures for 1959 and 1964 data are the same for 3) and 6) as well. A further explanation for items 12), 13) and 14) is needed. While data for these classes were collected in the 1964 census, they were not in 1959. It was assumed that relevant ratios which were found in 1964 were the same in 1959. These ratios are:

i) the proportion of "total number of hogs and pigs" which were "swine used for breeding";

ii) the proportion of "chickens over four months in age" which were "broilers"; and

iii) the proportion of "chickens over four months in age" which were "other chickens for slaughter."

These proportions were assumed to have held for 1959, making the respective computations as follows: (1959/13692)(14789), (1906/19504)(26701) and (12822/19504)(26701).

It is to be noted that the various ratio estimates used in the animal unit calculations are based upon state level data. Thus, to use these ratios for substate calculations implicitly assumes uniformity across the state. This seems to be a reasonable approximation of reality.

After the number of livestock in each of the various classes have been ascertained (actual) or derived (estimated), it remains to convert these numbers into grain- or concentrate-animal units. The factors for accomplishing this conversion are given in Table 6. Factors for various livestock classes are given for 48 states and the United States. With but three exceptions, the factors used in the 1964 and 1959 calculations are for Iowa. The factors for "sheep and lambs on feed" and "broilers" are national figures. The refinement step which separated "cattle on feed" and "calves on feed" was undertaken in this research because it was expected that the former class would require more feed than the latter. The Iowa Farm Planning Manual was consulted for an estimate of the expected difference. High-quality steer calves (450 lbs. = beginning weight), under full-fed plan, were found to require 53.6 bushels of corn equivalent while being fattened for market; similar yearlings (675 lbs. = beginning weight) were found to require 74.1 bushels of corn equivalent. Since the Iowa conversion factor for "cattle on feed" into animal units is 2.5, the conversion factor for "calves on feed" was estimated to be (53.6/74.1)(2.5) = 1.8.

The number of animal units from each of the 16 categories could then be computed. Next the 16 animal unit figures were aggregated into an over-all scalar representing the total. This has been done for 1964 and 1959 census data in Tables 8 and 9.

One check on the procedure applied to census data is to compare results with the USDA calculations for Iowa. While census calculations are for the calendar year, the USDA results are for the feeding year beginning October 1. For instance, the USDA figure for 1963 is from October 1, 1963 to September 30, 1964. Three-fourths of the 1964 calendar year is contained in the 1963 reported figure. Comparability can be achieved by a weighting procedure thus: (3/12) (1964 result) plus (9/12)(1963 result). The USDA results for Iowa which pertain to 1959 and 1964 comparisons follow:

Year	Iowa animal units ('000)
1958	24,709
1959	23,940
1963	24,449
1964	23,710

Calculating the 1964 and 1959 USDA calendar year figures, we have:

USDA (1964) = (3/4)(24,449) + (1/4)(23,710) = 24,264

USDA (1959) = (3/4)(24,709) + (1/4)(23,940) = 24,517.

Comparing the results of the present study with the USDA results, we find only a small difference:

	1964 (Iowa)	1959 (Iowa)
Present study	25,349	24,074
USDA result	24,264	24,517
Difference	1,085	443

The differences, expressed as percentages, emphasize their negligible magnitude:

1964 : (1,085/25,349)(100) = 4.3%

1959 : (443/24,074)(100) = 0.2%

The state totals, for the two procedures, compare very favorably. This is a crucial result since the previously defined animal unit calculation procedure is to be used at the substate (county) level where empirical checks are not readily available.

It is of interest to note that the United States Department of Agriculture has developed another procedure, in addition to animal units, for measuring the balance between livestock numbers and feed consumption [USDA Statistical Bulletin 337, 1964]. "Livestock production units" are calculated and used. Feed consumed per year by one milk cow producing 4,380 pounds of milk is used as a base (same base as for the animal unit calculations). On a national basis, the production-unit series seems to follow trends in feed consumption somewhat more closely than the animal-unit series. Presumably the former series reflects changes in feed efficiency, substitution of feed for other farm resources, restricted feeding and feeding of livestock to heavier or lighter weights more precisely than the latter series. However, the difference is not great. The animal-unit series was used because its calculation is disaggregated to the state level whereas the production-unit series is not. Since census data were used in order to obtain estimates at the county level, it was exceedingly useful to check the calculation of animal units aggregated to the state level against state-level estimates made by the USDA.

The procedure for calculation of animal units for each of Iowa's 99 counties is analogous to the procedure for state totals. An animal unit figure is obtained for each of the 16 livestock classes in each county. Computer programs were written to obtain census data from tapes and perform the animal unit calculations.

3. Feed requirements

There are two important aspects of the calculated animal-unit figures. They are a basis for estimating feed required (demand for feed) and they are a basis for county disaggregation of state totals.

The USDA annually derives a coefficient relating tons of feed required to animal units. The accompanying table traces the magnitude of this coefficient from 1950 to 1964. Over time there has been a general tendency to feed more concentrates per animal unit. Relating the coefficients for 1964 and 1959 animal unit calculations, one can arrive at estimates of feed required. For the state of Iowa we have:

1964 : (25,349)(0.87) = 22,054

1959 : (24,074)(0.85) = 20,462

These figures are in thousands.

The estimated Iowa demand for concentrate feeds expanded from about 20 1/2 million tons in 1959 to about 22 million tons in 1964.

Table 10. Concentrate feed fed per animal unit, 1950-64[a,b]

Year	Tons per animal unit	Year	Tons per animal unit
1950	.75	1958	.83
1951	.75	1959	.85
1952	.77	1960	.89
1953	.74	1961	.91
1954	.76	1962	.92
1955	.74	1963	.89
1956	.76	1964	.87
1957	.77		

[a]The coefficients are derived for the feeding year (beginning October 1); thus, the calendar year figure cited here is that designated by the previous year's October 1 date.

[b]Sources: USDA Statistical Bulletin 337, 1964, p. 27; USDA Statistical Bulletin 337 Supplement, 1967, p. 13; and USDA Feed Situation, February 1967, p. 7.

These estimates refer to complete feeds. The results for each of Iowa's 99 counties are presented in Appendix A.

The feed requirement or tons per animal unit is a coefficient based on "national data." The computation is a comparison with supply of feed -- called the feed balance calculation. This annual calculation by the USDA is published in FEED SITUATION. The supply of concentrate feeds is the sum of quantity of feed grains produced, carry-over stocks, quantity of by-product feeds and feed in parts [USDA Handbook 118, 1957, p. 59]. The supply is allocated to quantity fed to livestock, all other uses and stocks to be carried over into the next year. When compared to supply of feed for livestock (i.e., after subtracting carry-over stocks and other uses volume), animal unit numbers allow calculation of a number-to-supply balance for any year.

The feed supply for livestock is divided by the number of animal units to compute the tons-per-animal-unit feed requirement coefficient.

4. Disaggregation by product form

As has been noted previously, the present study's magnitude of demand estimates for feed in Iowa corresponds closely to USDA estimates. It has also been noted that these demand magnitudes refer to complete feeds. However, much commercial feed tonnage is in the form of supplements rather than complete feeds. In feed grain surplus states such as Iowa, the fraction of total feed purchased which is in supplement form is particularly high. Earlier, in describing the feed industry and Iowa agriculture (Chapter II), two product-form conclusions were documented: much of commercial mixed feed is supplement, and the fraction in Iowa is relatively high. The consequence of these conclusions is that some adjustment is imperative if realistic estimates of feed tonnage volumes are to be derived. The actual feed volumes are partly supplement and partly complete feed tonnages. A procedure is needed to disaggregate the above-derived feed tonnage estimates into supplement feed tonnages and complete feed tonnages.

The Iowa Department of Agriculture commercial feed tonnage data are separated between supplement and complete feeds for most classes of livestock. Their data were used as a basis for disaggregating the estimates of the present study into tonnages of supplement and complete feeds. The data for 1964 will be calculated.

The basic logic followed in the disaggregation procedure will be outlined and subsequently each step will be described in detail. The basic idea was to convert Iowa Department of Agriculture data on supplement tonnages into complete feeds and add the results to complete feed tonnages reported; then the proportions of this total of supplement "source" and complete feed "source" could be found and applied to the estimates of the present study. As a consequence, the present study feed estimates could be divided into complete feed and supplement "sources" and the latter converted from complete to supplement feed tonnages. A major data requirement of this procedure is percentages of supplements in the respective rations of each of the 16 livestock classes for which feed tonnages were derived.

The four basic steps of the procedure will be detailed presently: i) obtain ration coefficients for each of the 16 livestock classes indicating the fraction of the total ration which should be supplement; ii) using these coefficients, transform the Iowa Department of Agriculture data into complete feeds only estimates; iii) using the derived complete feed estimates for this Iowa data, disaggregate the estimates of the present study into complete feed and supplement feed tonnages; and iv) sum the tonnages of these two product forms into one commercial mixed feed tonnage estimate for the present study. The result will be a tonnage estimate for each of the 16 livestock classes for each county.

a. Supplements as percentages of total concentrates The relationships developed in this section are based upon recommended rations.

Hence, there is some normative connotation to the coefficients. It is likely that actual feeding practices in Iowa deviate somewhat from the relationships which are developed herein. The ration information was obtained from the Livestock Feeding section of the IOWA FARM PLANNING MANUAL and from F. B. Morrison's FEEDS AND FEEDING.

The Iowa Department of Agriculture groups its livestock feeds into chickens, turkeys, swine, beef, dairy, calf, sheep and horse feeds. Since the present study has developed a more detailed livestock breakdown, some reconciliation was necessary. The chicken feed would serve the needs of broilers (BR13), chickens over four months of age (C10OLD) and other chickens for slaughter (OC14SL). Turkey feed would go to breeding flocks (T11BR) and turkeys raised for sale (TUR15R) while the hog feed breakdown would be similar (SW12BR and HOG16S). Beef cattle feeds included feed for beef cows (B3COWS), cattle on feed (FINV4L) and calves on feed (FINV5S) while dairy feed included feed for milk cows (M1COWS) and milk heifers (MH2HC); the feed for "other cattle" (OTH6) was allocated between beef and dairy according to the relation of beef animal units to dairy animal units. Sheep feeds consisted of feed for breeding stock (ST8SH) and sheep on feed (FD9SH). Exact correspondence existed for horse (and mule) feeds (H7M).

Chicken supplements: For the purposes of this study, it was assumed that broiler raisers would purchase only complete feeds; therefore, the supplements would be purchased to feed the other two chicken classes. Animal unit results compiled from census livestock and poultry numbers suggest that most of these chickens are layers and old layers slaughtered. Rations for chickens are given in the IOWA FARM PLANNING MANUAL. A ton of 16 percent (protein) complete ration for layers results from 800 pounds of 27 percent supplement and 1,200 pounds of corn. This is a ration which is 40.00 percent supplement. Thus, SUPCHK = 0.4000. SUPCHK is the ration coefficient for chickens. Using 1964 as an example, 182,386 tons of supplement for chickens would yield 182,386 ÷ 0.40 = 455,964 tons of complete feed.

Turkey supplements: A 16 percent (protein) ration is recommended for mixed turkey flocks at 16 to 20 weeks of age [Iowa Farm Planning Manual, 1963, p. 56]. A supplement to grain (corn) relationship of 35 : 65 yields the recommended ration. The percentage of the total ration which would be supplement is 35.00 percent, or SUPTKY (turkey ration coefficient) = 0.3500. Again using the 1964 example, 87,488 tons of turkey supplement would yield 249,966 tons of complete feed for turkeys.

Swine supplements: The nutritional requirements of swine breeding stock and hogs being fed for market differ to an extent justifying separate treatment in this analysis. Based on estimated feed requirements for hogs from birth to market weight [Hays, 1963], rations are recommended containing a total of 104.9 pounds supplement (35 to 37 percent protein grower concentrate) and 584.1 pounds of corn [Iowa Farm Planning Manual, 1963, p. 42]. This ration would contain 14 to 15 percent protein on the average (i.e., average over the lifetime of the market hog). The level of supplement in the ration would be $104.9 \div (104.9 + 584.1) = 15.22$ percent, or SUPS16 = 0.1522. Obtaining a composite figure for the swine breeding herd was more complicated. Three distinct types of feed needs were analyzed: nonlactating sows, lactating sows (lactation period is about 56 days per year for rearing two litters) and boars (one boar per 40 sows is assumed). The feed requirements per year follow:

	Grain (corn) (pounds)	Supplement (pounds)
Nonlactating sow	728	88
Lactating sow	504	168
Boar	1,278	548

The assumed environment is that of pasture rather than drylot. The respective fractions which are supplements can now be computed:

Nonlactating sow: $$\frac{88}{728 + 88} = \frac{88}{816} = 10.78\%$$

Lactating sow: $$\frac{168}{504 + 168} = \frac{168}{672} = 25.00\%$$

Boar $$\frac{548}{1278 + 548} = \frac{548}{1826} = 30.01\%$$

In order to obtain a composite percentage supplement figure for a breeding herd, some sort of an average is needed. The simple average would be a distortion because only one boar is needed for 40 sows. A weighted average was computed using feed requirements per <u>herd</u> as the weighting coefficients (dividing the feed needs of the boar by 40 -- that is, $\frac{1826}{40} = 46$). The weighted average was computed as follows:

$(\frac{816}{1534})(10.78) + (\frac{672}{1534})(25.00) + (\frac{46}{1534})(30.01 = 17.59\%$, where

$1534 = 816 + 672 + 46.$

The ration coefficient will be referred to as SUPS12 = 0.1759.

Cattle supplements: The class "other cattle," which is allocated between beef and dairy, is assumed to use feed in which the supplement content is 10 percent. That is, SUPOT6 = 0.1000. This assumption is arbitrary but the class is a "catch-all" whose precise content is heterogeneous. Numerically, the class is relatively unimportant.

For beef cattle not being fattened, little supplement is fed if good hay is available. Some supplement is fed, however, with silage, ground corncobs, poor hay or straw [Morrison, 1956, p. 733]. This is especially true during lactation and gestation if good pasture also is unavailable. In this analysis it is assumed that no commercial complete feed is bought for beef cows. Rations suggested by Morrison indicate that nutritional needs would be met adequately if 5 percent (SUPBF3 = 0.0500) of total concentrates fed was supplement.

Total feed requirement data were found for cattle on feed [Iowa Farm Planning Manual, 1963, pp. 34-35]. For yearling steers, 74.1 bushels of corn equivalent and 480 pounds of 32 percent supplement comprises the ration concentrates recommended. The corresponding figures for heifers are 21.0 bushels and 182 pounds. It is to be noted that heifers are smaller, are held in the feedlot for a shorter period of time and are finished at lighter weights. The respective calculations of supplement as a proportion of total concentrates are:

$$\text{Steers:}\quad \frac{480}{((74.1)(56) + 480)} = \frac{480}{4630} = 10.38\%$$

$$\text{Heifers:}\quad \frac{182}{((21.0)(56) + 182)} = \frac{182}{1360} = 13.39\%$$

Assuming a 50 : 50 sex distribution, the representative percent of total concentrates which would be 32 percent supplement is:

$$(1/2)(10.37) + (1/2)(13.38) = 11.89\%$$

Therefore, SUPFD4 = 0.1189.

The IOWA FARM PLANNING MANUAL also gives feed requirement data for steer and heifer calves. They are 53.6 bushels of corn equivalent to 420 pounds of 32 percent supplement for steers, and 34.1 bushels to 280 pounds of supplement for heifers, calculations become:

$$\text{Steers:}\quad \frac{420}{((53.6)(56) + 420)} = 12.28\%$$

$$\text{Heifers:}\quad \frac{280}{((34.1)(56) + 280)} = 12.78\%$$

Again assuming half steers and half heifers, a composite figure can be represented as the average:

$$(1/2)(12.28) + (1/2)(12.78) = 12.53\%$$

The SUPFD5 ration coefficient thus equals 0.1253.

Feed requirements for dairy cattle are difficult to typify. This is particularly true for dairy cows; quantities, kinds and qualities vary between farms, breeds of cattle, levels of production and levels of farm management. The dairy cow ration for medium-quality forage was chosen to represent the Iowa situation. This ration calls for 200 pounds of 32 percent supplement per ton of total concentrates [Iowa Farm Planning Manual, 1963]. The figure sought is therefore 20.00 percent, or SUPMK1 = 0.2000.

For milk heifers, a ration [Morrison, 1956, p. 1116] for heifers over six months of age with fair- to good-quality forage (one-half legume) was used; the ration contains 225 pounds of soybean oilmeal supplement per ton of total concentrates. The percentage supplement or ration coefficient is calculated as

$$\frac{225}{2000} = 11.25\%, \text{ so SUPMH2} = 0.1125$$

Sheep supplements: The estimated feed requirements per breeding ewe and lamb to weaning depends on whether early or late lambing is practiced. According to extension people, the larger producers tend to lamb early, while most producers tend to lamb late; they expect the numerical division to be about even. The early lambing relationship is about 500 bushels of corn equivalent per ton of supplement whereas the respective late lambing figures are 300 bushels per 1,500 pounds. The calculation for early is $\frac{2000}{((500)(56) + 2000)} = 6.67\%$ and for late is $\frac{1500}{((300)(56) + 1500)} = 8.19\%$. The average (SUPSH8) is 7.43 percent (0.0743).

Feed requirement estimates are available for fattening feeder lambs [Iowa Farm Planning Manual, 1963, p. 50]. A feeder lamb purchased at 75 pounds and fed 75 days to a market weight of 100 pounds will require concentrates consisting of about 2.2 bushels of corn and 15 pounds of supplement. Calculating the ration coefficient in the concentrate ration, we obtain

$$\frac{15}{((2.2)(56) + 15)} = 10.85\%, \text{ or SUPSH9} = 0.1085$$

Horses and mules supplement: It was assumed that all feed purchased for this class of livestock is supplement and that it is fed as 10 percent of the ration; consequently, SUPHM = 0.1000. The chief ration provision should be a liberal supply of total digestible nutrients (or net energy); a ration relatively low in protein and moderately low in vitamins and minerals is satisfactory [Morrison, 1956, p. 824]. Where Morrison calls for supplements in his example horse rations, he suggests about a 9 : 1 ratio with grain.

b. Derivation of complete feed only estimates Iowa Department of Agriculture tonnage data were presented in Table 4. Consider the 1964 vector (denoted here as IDOA) in more detail -- elements one through 13 are livestock feed classifications, while element 14 is the 1964 total tonnage. The total is partly supplement and partly complete feed tonnages. The objective of this section is to describe how this vector is transformed into a vector in which all elements refer to complete feeds. This vector will be referred to as CPIDOA. The transformation is accomplished by leaving the elements which refer to complete feeds unchanged but multiplying supplement elements by the reciprocals of ration coefficients to convert into complete feeds. In matrix notation, the procedure is IDOA • RRC = CPIDOA, where RRC is a diagonal matrix of ration coefficient reciprocals; that is, RRC = diag [1 x 1 x 1 x 1 x 1 x x x x] - the off-diagonal elements are zero and small x denotes the weighted ration coefficient reciprocal. The unit elements leave the IDOA element unchanged in the transformation to CPIDOA; this applies to complete feed elements for chickens, turkeys, swine, beef cattle and dairy cattle. Table 11 presents the 1964 IDOA and CPIDOA vectors of feed tonnages.

For converting supplements into complete feeds for chickens, turkeys and horses and mules, the method is straightforward. The transformation coefficients are the simple reciprocals of the respective ration coefficients. For instance, the turkey transformation coefficient (RRC_{44}) is 1/SUPTKY = 1/0.35 = 2.86.

The remaining five transformation coefficients were found by weighting ration coefficients according to animal unit magnitudes within each of the IDOA livestock classes.

For swine there were two sources of demand for feed -- breeding stock and market hogs raised (SW12BR and HOG165). Each of these two variables had been converted into standard animal units. By summing the two into total swine animal units, it was possible to find what proportion of total swine animal units was due to breeding stock and due to fattening hogs. These two ratios were used to divide the Iowa Department of Agriculture total swine supplement tonnage, IDOA(6), into supplement tonnage due to these two sources of demand. Finally, by multiplying these two separated swine supplement tonnages by the reciprocals of their ration coefficients from the preceding section (1/SUPS12 and 1/SUPS16), two complete feed tonnage estimates were derived. It remains merely to add the two results and the swine complete feeds figure derived from swine supplements, CPIDOA(6), is at hand.

Table 11. 1964 summary of results of converting Iowa Department of Agriculture feed tonnages into complete feeds only

Element number	Feeds description	IDOA	CPIDOA
		(tons)	(tons)
1	Chickens (complete)	119,499.32	119,499.32
2	Chickens (supplements)	182,385.79	455,964.50
3	Turkeys (complete)	53,583.37	53,583.37
4	Turkeys (supplements)	87,487.93	249,965.54
5	Swine (complete)	403,027.30	403,027.30
6	Swine (supplements)	830,196.13	5,387,146.60
7	Beef (complete)	65,071.44	65,071.44
8	Beef (supplements)	474,512.74	4,577,232.16
9	Dairy (complete)	18,158.36	18,158.36
10	Dairy (supplements)	77,627.26	488,047.46
11	Calf	21,334.99	117,342.48
12	Sheep	3,676.84	41,308.86
13	Horse	1,233.97	12,339.70
14	Total tonnages	2,337,795.44	11,988,687.10

The procedure for sheep is exactly analogous except for different variables (ST8SH and FD9SH), their respective ration coefficients from the preceding section and element IDOA(12) from the 1964 Iowa Department of Agriculture commercial feed tonnage vector.

The method for handling beef cattle and dairy cattle is more complicated but yet analogous. The animal units due to "other" animals were allocated to beef and dairy as described earlier. Beef cattle supplement was allocated into four sources of demand (B3COWS, FINV4L, FINV5S and OTH6) according to proportions of total beef animal units accounted for by each. Three sources of demand accounted for the dairy supplement total, namely M1COWS, MH2HC and OTH6. Each was converted into derived complete feed only tonnage and summed to obtain derived total beef, CPIDOA(8), and derived total dairy, CPIDOA(10), cattle tonnages. It was assumed that one-half of calf feed would be complete and the remainder supplement fed at a 10 percent level of total concentrates. In Table 11, IDOA refers to 1964 commercial tonnage figures from the Iowa Department of Agriculture. The vector name CPIDOA refers to complete feeds reported and complete feeds derived from supplement tonnages reported.

c. Disaggregation of present study feed estimates The estimates of the present study thus far developed are complete feed estimates for each county for each of the 16 livestock classes. The objective of this step is to divide each of these estimates into product forms expected to be purchased. For the typical feed estimate one would expect part of the tonnage to be purchased as complete feed but the remainder in supplement form. For each estimate of the present study, the problem is to ascertain the expectation of what fraction will be purchased from the feed industry in complete feed form and what fraction will be in supplement form. The tonnage of supplements needed to balance (with grain) complete rations must then be found; the ration coefficients developed previously are used.

The transformation of feed estimates into complete feed tonnages and supplement feed tonnages will be detailed for each of the 16 livestock feed-demand variables. The complete feed component is derived simply. For example, recall that the vector of derived-complete feed tonnages contains two chicken entries for chicken complete feeds -- one of "complete" feed source, CPIDOA(1), and one of "supplement" source converted into complete feeds, CPIDOA(2). The feed estimates for C10OLD and OC145L were fractured into complete and supplement sources by the respective fractions $\frac{\text{CPIDOA(1)}}{\text{CPIDOA(1)} + \text{CPIDOA(2)}}$ and $\frac{\text{CPIDOA(2)}}{\text{CPIDOA(1)} + \text{CPIDOA(2)}}$. The complete feed tonnage is estimated directly in this manner. The estimated supplement tonnage requires one more step -- multiplication by the appropriate supplement-to-total concentrates ration coefficient. For chickens this coefficient is SUPCHK. Broilers are assumed to be fed only purchased complete feeds so no transformation is necessary.

The separation calculation for turkeys is similar except that the weighting fractions are derived from elements 3 and 4 of the vector CPIDOA and feed estimates for variables T11BR and TUR15R are allocated. The appropriate ration coefficient, namely SUPTKY, must be applied to obtain the supplement tonnages.

Analogous application of the above method, using appropriate data and coefficients, will disaggregate the feed estimates into complete and supplement feed tonnages for the other livestock variables; swine, beef cattle, dairy cattle, sheep and horses and mules feed estimates thus are separated. Observe that an assumption of supplements only purchased manifests into zero complete feed tonnages for beef cows (B3COWS), "other cattle" (OTH6), horses and mules (H7M), stock sheep (ST8SH) and sheep on feed (FD9SH).

The disaggregation procedure described herein is applied to each county for each livestock variable. The basic result is the disaggregation of a 99 x 16 feed-estimates matrix into two 99 x 16 matrices -- one of complete feed tonnages and the other of supplement feed tonnages. A total tonnage matrix could be obtained by summing the complete feed and supplement feed tonnage matrices. These numerical results are not presented. They are subject to comparability adjustments; these adjustments are the focus of the ensuing section.

5. Comparability adjustments and final tonnage estimates

As a consequence of applying the procedural steps outlined, the state total feed estimate of 4,712,673 tons is separated into 1,422,660 tons of complete feed and 3,290,013 tons of supplement feed.

State-level data on feed requirements and/or feed production and/or feed purchases are available from several sources. These figures vary rather widely from one source to another and attention should be given to reconciliation of the various estimates. The objective of this section is to examine and relate the feed estimates from several sources.

It was noted earlier that the total feed concentrate requirements estimated for Iowa corresponded very closely with those of the USDA.

Two data sources report feed tonnages of combined product form (that is, complete feed and supplement feed tonnages lumped into a single reported tonnage figure). The 1964 Census of Agriculture reported Iowa farmer purchases of commercially mixed feeds, millfeeds and supplements to be 2,611,233 tons. The State Department of Agriculture commercial feed tonnage figure for 1964 is 2,337,795 tons. Assuming the sheep, horse and half the calf feed to the supplements, this figure breaks down into 670,007 tons of complete feed and 1,667,788 tons of supplement. These figures differ from the estimates of the present study.

However, commercial feed production tonnages are also published yearly by the Bureau of the Census in a special series [Current Industrial Reports, 1963-65]. Feed tonnages are reported separately for complete and supplement feeds. Unfortunately, while complete feed tonnages are reported at the state level, supplements are reported only regionally. Two "complete" figures are reported: $2458(X10^3)$ tons including feeds mixed on custom basis, and $1116(X10^3)$ tons excluding custom mix tonnage and feed produced by establishments for their own feeding purposes. The production of supplements in the West North Central region was $3955(X10^3)$ tons.

The complete feed figure desired for comparability is something other than either of the two offered. A figure which excludes custom-mix feed but includes feed manufactured for use at the same location (the situation fitting many large, integrated operations) would be more comparable -- the magnitude of such a complete feed tonnage figure would lie between the two figures offered. The regional supplement tonnage allocation for Iowa needs to be determined. Using total production figures as a basis for allocation, the share of regional tonnage for Iowa was estimated to be $(\frac{2458}{7655})(3955) = 1270$ $(X10^3)$ tons. Summing the complete and supplement estimates, we have $1116 + 1270 = 2386(X10^3)$ tons of feed.

It is clear that the Census of Agriculture, Iowa Department of Agriculture and Current Industrial Report estimates differ not only from estimates of the present study but from each other. Table 12 summarizes these feed tonnage results. There is a fundamental

Table 12. Feed tonnage estimates for Iowa, 1964

Source	Complete	Supplements	Total
	('000)	('000)	('000)
Present study	1,423 (100%)	3,290 (100%)	4,713 (100%)
Current Industrial Report	1,116 (78%)	1,270 (39%)	2,386 (51%)
Census of Agriculture	--	--	2,611 (55%)
Iowa Department of Agriculture	670 (47%)	1,668 (51%)	2,338 (50%)

difference between the estimates of the present study and the other three sources. Different things are measured. The estimates of the present study might be regarded as estimates of potential feed demand for the feed industry since the basis for the estimates is livestock numbers. The other three estimates are based on data reflecting production and purchases which actually took place in 1964. In a context of feed demand which is accessible demand for the formula feeds industry, there are reasons to expect that the present study estimates are too high. On the other hand, there are reasons to expect that each of the other three estimates are too low. These reasons will now be considered in detail.

There are two major reasons to expect that the potential feed demand estimates suggested by the present study are not entirely accessible demand for the commercial mixed-feeds industry. There is still livestock that is fed no feed of commercial source; these livestock numbers would enter into the present study estimates but none of the other three estimates. In addition, the rations used (and the supplement component of each ration) were based on recommended nutritional levels. These coefficients should be regarded as upper bounds; few farmers would feed beyond recommended levels, but it is likely that many would feed less. This reasoning would apply to total concentrates fed per animal unit and even more so to the proportion of the total ration which is supplement in nature. It is, however, difficult to know the magnitude that the present study estimates should be discounted.

The Census Bureau explicitly recognizes that the Current Industrial Reports data should be regarded as minimums. There are two reasons for this: i) they feel it is likely that the coverage of their survey is incomplete, and ii) the digital Standard Industrial classification of manufacturing establishments is used (2042 for prepared animal and poultry feeds) -- an establishment must be engaged primarily in the feed manufacturing activity to be included. There are several company's establishments producing feed whose primary activity is other than manufacturing feed.

The tonnage data compiled by the Iowa Department of Agriculture relates to feed tonnage which is taxed -- that is, tonnage on which the inspection fee of ten cents per ton is paid. It seems reasonable to expect these tonnage totals to be biased downwards.

Finally, there may be some reason to consider Census of Agriculture data as minimums. It seems likely that the farmer would have a more accurate record of the number and kinds of livestock he has (revenue side) than feed purchases he has made during the year (cost side). It also seems reasonable to suppose that errors in reported livestock numbers might be normally distributed while those relating to feed purchases might be biased toward underestimation.

To fulfill the objectives of this research effort, a set of estimates is needed which realistically describe the feed demand which is accessible market demand for the commercial formula feeds industry. Estimates for each county were desired. Qualitatively, it is clear that the feed estimates thus far generated in the present study are high and the estimates from each of the other three sources are low. The real question is the quantitative one of "how much."

The problem would best be resolved by surveying representative farms of representative counties in order to get more complete and detailed information. However, if this is beyond the scope of available time and resources, some arbitrary decisions need to be made. Complete and supplement feeds were treated separately. An arbitrary decision was made for each. The adjusted estimate for complete feeds was taken to be 85 percent and for supplements 70 percent of the previously estimated tonnage to be supplied. Two 99 x 16 adjusted tonnage matrices were calculated, one for adjusted complete feed tonnages and the other for adjusted supplement feed tonnages.

The final adjusted matrix of tonnages per livestock class per county is found by summing the complete and supplement tonnage matrices. The final adjusted matrix of tonnages to be supplied in the model is presented in Appendix B. Each element in the matrix refers to a particular livestock variable in a particular county.

Table 13 presents the county totals and the state total of animal units, unadjusted complete and supplement feed tonnages, adjusted complete and supplement feed tonnages and final estimated feed tonnages to be supplied. Table 14 contains livestock variable state totals for the same six items as in Table 13. The names of the 16 livestock variables correspond to those designated in Tables 8 and 9.

C. Iowa Transportation Matrix

Development of a road mileage transportation matrix for Iowa was necessary to fulfill the research objectives of the present study. Since both transportation and selling costs varied with distance, distance relationships were essential ingredients in computing distribution costs. The procedure detailed below was developed by the author.

TABLE 13. COUNTY TOTALS AND STATE TOTAL. ANIMAL UNITS, UNADJUSTED COMPLETE AND SUPPLEMENT FEED TONNAGES, ADJUSTED COMPLETE AND SUPPLEMENT FEED TONNAGES, AND ESTIMATED TONNAGES TO BE SUPPLIED

COUNTY	ANIMAL UNITS AND RELATED TONNAGES					
	AN UNITS	UNADJ CF	UNADJ SF	ADJ CF	ADJ SF	TONNAGE
ADAIR	231209	12581	29085	10694	20359	31053
ADAMS	148723	8127	18533	6908	12973	19881
ALLAMAKEE	219940	12510	29473	10633	20631	31265
APPANOOSE	89740	4430	10813	3765	7569	11335
AUDUBON	273330	14149	34963	12027	24474	36501
BENTON	432372	22582	53972	19195	37780	56975
B K HAWK	287220	17024	38984	14470	27289	41759
BOONE	233698	14069	31627	11959	22139	34098
BREMER	208201	14307	30895	12161	21626	33787
BUCHANAN	278379	16363	37130	13909	25991	39900
B VISTA	313608	18406	41599	15645	29119	44764
BUTLER	282808	17968	39235	15273	27464	42737
CALHOUN	206711	11542	26889	9811	18822	28633
CARROLL	386473	20360	49224	17306	34457	51763
CASS	264404	12962	32584	11018	22809	33826
CEDAR	466301	24540	57666	20859	40366	61225
C GORDO	270294	17920	37827	15232	26479	41711
CHEROKEE	355608	16518	43738	14040	30617	44657
CHICKASAW	223310	14525	31589	12346	22112	34459
CLARKE	110355	6341	14146	5390	9902	15292
CLAY	235212	11821	29567	10048	20697	30745
CLAYTON	345961	19871	46151	16890	32306	49196
CLINTON	486503	22811	59036	19389	41325	60715
CRAWFORD	377018	20211	48329	17179	33830	51010
DALLAS	221184	12561	28408	10677	19886	30562
DAVIS	98111	5464	12227	4644	8559	13203
DECATUR	92873	4756	11420	4043	7994	12037
DELAWARE	402742	24516	54325	20839	38027	58866
D MOINES	154575	8674	18945	7373	13261	20634
DICKINSON	131066	7370	17473	6264	12231	18496
DUBUQUE	354502	20364	46175	17309	32322	49632
EMMET	130164	6819	16676	5796	11673	17469
FAYETTE	314182	18929	43294	16090	30306	46395

TABLE 13 (CONTINUED)

COUNTY	AN UNITS	UNADJ CF	UNADJ SF	ADJ CF	ADJ SF	TONNAGE
	ANIMAL UNITS AND RELATED TONNAGES					
FLOYD	209144	13483	29309	11461	20516	31977
FRANKLIN	323190	18948	43141	16106	30199	46304
FREMONT	108982	4530	12701	3850	8891	12741
GREENE	207089	10921	26052	9283	18236	27519
GRUNDY	293882	16532	38284	14052	26799	40851
GUTHRIE	196346	11191	25461	9512	17823	27335
HAMILTON	324977	24855	50326	21127	35228	56355
HANCOCK	275332	18306	39095	15560	27366	42927
HARDIN	319253	18011	41646	15309	29152	44462
HARRISON	183113	8788	22267	7470	15587	23057
HENRY	222123	15175	31210	12899	21847	34746
HOWARD	179323	11909	25653	10123	17957	28080
HUMBOLDT	172824	9760	22689	8296	15882	24178
IDA	285760	14632	36358	12437	25451	37888
IOWA	340935	18595	43193	15806	30235	46041
JACKSON	290088	14290	35840	12146	25088	37234
JASPER	359886	19350	45270	16447	31689	48136
JEFFERSON	145960	8119	18307	6901	12815	19716
JOHNSON	371119	23308	49706	19812	34794	54606
JONES	376063	18985	46695	16137	32686	48824
KEOKUK	303480	18474	39673	15703	27771	43474
KOSSUTH	403134	24573	54847	20887	38393	59280
LEE	161188	9278	20609	7886	14426	22313
LINN	307020	18065	39210	15355	27447	42802
LOUISA	164968	9212	20698	7830	14489	22319
LUCAS	101807	5913	13183	5026	9228	14254
LYON	305447	15860	39666	13481	27766	41247
MADISON	176828	9333	21590	7933	15113	23046
MAHASKA	327275	18599	41281	15809	28897	44706
MARION	243001	13017	30346	11064	21242	32307
MARSHALL	279712	13348	34183	11346	23928	35274
MILLS	157109	6883	18754	5851	13128	18978
MITCHELL	250832	15245	34707	12958	24295	37253

TABLE 13 (CONTINUED)

COUNTY	ANIMAL UNITS AND RELATED TONNAGES					
	AN UNITS	UNADJ CF	UNADJ SF	ADJ CF	ADJ SF	TONNAGE
MONONA	172360	8760	21239	7446	14867	22313
MONROE	84567	4405	10304	3744	7213	10957
M TGOMERY	197910	9575	24070	8139	16849	24988
MUSCATINE	229969	12338	28666	10487	20066	30553
O BRIEN	306838	17918	39797	15230	27858	43088
OSCEOLA	177197	9502	23199	8077	16239	24316
PAGE	234225	11241	28290	9555	19803	29358
PALO ALTO	208279	11425	26937	9711	18856	28567
PLYMOUTH	550372	30134	70830	25614	49581	75195
P HONTAS	243822	14362	32730	12208	22911	35119
POLK	140807	8472	18898	7201	13229	20430
POTT MIE	493924	20335	58418	17285	40893	58177
POWESHIEK	272300	14528	34002	12349	23801	36150
RINGGOLD	124949	6448	15306	5481	10714	16195
SAC	347981	17003	43320	14453	30324	44777
SCOTT	311669	17246	39660	14659	27762	42421
SHELBY	332078	16529	41756	14050	29229	43279
SIOUX	577225	29381	73560	24974	51492	76466
STORY	251481	15828	34038	13454	23827	37280
TAMA	381219	20607	48269	17516	33788	51304
TAYLOR	154969	8155	19191	6932	13434	20365
UNION	121303	6256	14772	5318	10340	15658
VAN BUREN	116119	6745	14890	5733	10423	16156
WAPELLO	107366	5890	13330	5006	9331	14337
WARREN	164287	9493	21285	8069	14899	22969
WASH TON	408660	27408	56502	23297	39551	62848
WAYNE	125172	7969	17328	6774	12130	18903
WEBSTER	177368	11242	24502	9556	17151	26707
WINNEBAGO	184746	13227	25383	11243	17768	29011
W SHIEK	332960	20702	46388	17597	32472	50068
WOODBURY	397456	20953	51460	17810	36022	53832
WORTH	177162	12877	24421	10945	17095	28040
WRIGHT	248411	16828	33327	14304	23329	37633
IA TOTAL	25349120	1422660	3290013	1209260	2303009	3512269

TABLE 14. LIVESTOCK STATE TOTALS. ANIMAL UNITS, UNADJUSTED COMPLETE AND SUPPLEMENT FEED TONNAGES, ADJUSTED COMPLETE AND SUPPLEMENT FEED TONNAGES, AND ESTIMATED TONNAGES TO BE SUPPLIED

LIVESTOCK VARIABLES	ANIMAL UNITS AND RELATED TONNAGES					
	AN UNITS	UNADJ CF	UNADJ SF	ADJ CF	ADJ SF	TONNAGE
M1COWS	882776	27550	148093	23417	103665	127082
MH2HC	190106	5933	17939	5043	12557	17600
B3COWS	498840	0	21700	0	15190	15190
FINV4L	3975562	48481	405480	41209	283836	325045
FINV5S	323759	3948	34799	3356	24359	27715
OTH6	945554	0	82263	0	57584	57584
H7M	113574	0	9881	0	6917	6917
ST8SH	46812	0	3026	0	2118	2118
FD9SH	51432	0	4855	0	3398	3398
C10OLD	1072698	193796	295781	164726	207046	371772
T11BR	13967	2144	3502	1823	2451	4274
SW12BR	1469264	88974	209195	75628	146437	222065
BR13	15251	13268	0	11278	0	11278
OC14SL	256447	46330	70711	39381	49498	88879
TUR15R	580806	89197	145636	75818	101946	177764
HOG16S	14912270	903037	1837151	767582	1286005	2053587

The results are in a context of the spatial definitions outlined in the first section of this chapter.

1. Procedure

Air miles can be converted into road miles quite accurately. Most of the United States and Canada are served by a rectangular road grid; the air to road miles conversion then is relatively straightforward and accurate. A rectangular road grid is found in Iowa.

The distances in air miles were measured between the 51 population centers and the reference points of Iowa's 99 counties. The 1966 official Iowa Highway Commission map of the state was used as a surface on which air mileages were measured. Calipers were used to measure "map surface distance" between each set of relevant points. These measurements were reflected as air miles by consulting the map's inches-to-miles scale. A total of 5,049 such measurements had to be made in order to complete the task. In addition, the "angle relationship" between points was noted. Existing road and highway channels were used with the exception of assuming a completed interstate highway system.

To get from one point to another, a road vehicle must travel more road miles than air distance. A conversion factor is needed. To illustrate, in Figure 11A, h would be measured as the air distance between X and Y, but the road distance would be $(a + b)$; $h < (a + b)$ or the air mileage is less than the corresponding road mileage. Figure 11B addresses the "how much" problem. The measured air distance, h, is the same in B as in A yet $(a + b) > (a' + b')$; more road miles must be traveled between X and Y than between W and Z. The significance of the "angle relationship," θ, is now apparent. The angle, θ, is positively related to the difference between road miles and air miles.

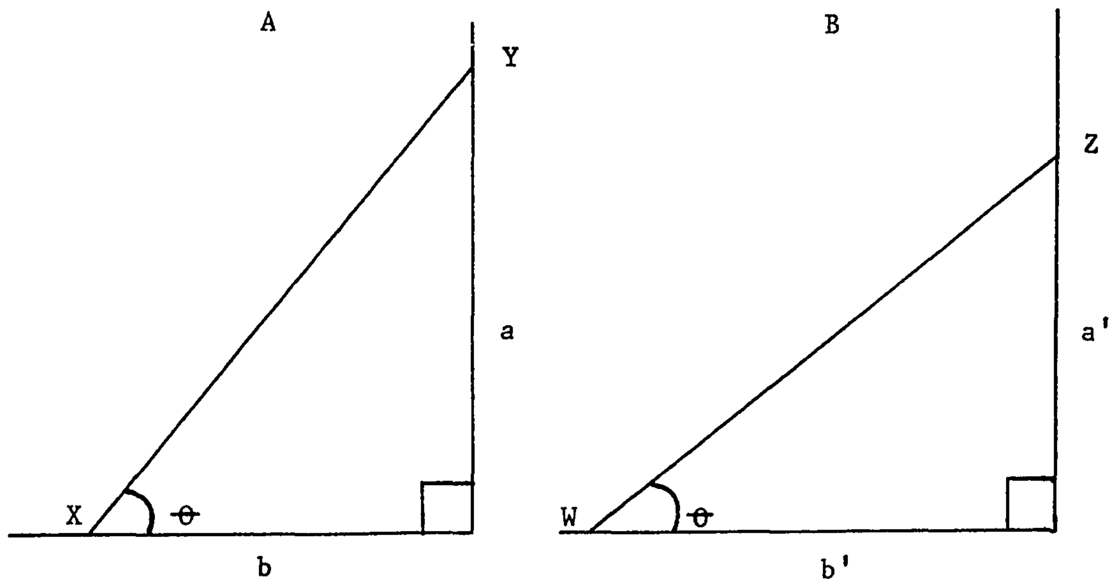

Figure 11. Relation of air miles to road miles

Assuming rational action, the relevant range of angles is from 0° to 45°. It would be irrational, when traveling to a point (say) northeast of one's origin, to travel further north or further east than one's destination. The angle relationship θ was stratified into five classes -- see Table 15. Obtaining a finer breakdown would have required greater cost than justified by the resulting greater accuracy.

The angle between each set of points was recorded to be one of the five strata. It can be seen that if θ = zero, h = (a + b), but b = 0 so h = a and the road distance equals the air distance. The magnitude of the air to road mileage conversion factor depended on the angle. A manipulation of trigonometric functions was required to accomplish the conversion. The procedure will be illustrated by

Table 15. Stratification of angle relationships between sets of points

Angle = θ	Range
0°	0° - 5°
10°	6° - 15°
20°	16° - 25°
30°	26° - 35°
40°	36° - 45°

referring to Figure 11A; h is air miles while a is road miles in one direction and b is road miles in another direction:

$$\text{Sine } \theta = a \,/\, h \tag{6.C.1}$$

$$\text{Cosine } \theta = b \,/\, h \tag{6.C.2}$$

Solving:

$$a = h \text{ sine } \theta \tag{6.C.3}$$

$$b = h \text{ cosine } \theta \tag{6.C.4}$$

$$\text{Road miles} = a + b$$

$$= h \text{ sine } \theta + h \text{ cosine } \theta \tag{6.C.5}$$

The respective values of θ used were 0°, 10°, 20°, 30° and 40°.

A computer program was written to perform the conversion. Angles had to be converted into radians since the computer's sub-program for trigonometric functions requires radians as arguments.

One further matter was taken into account. There are several important roads in Iowa which constitute exceptions to the rectangular road grid configuration. An obvious example is the diagonal highway between Des Moines and Marshalltown. Wherever the diagonal road exception was significant, the actual road miles between a set of points were determined. In all other cases, however, the two step procedure of measuring air miles and then making the appropriate (if any) conversion to road miles was followed.

2. Results

A 51 x 99 matrix containing air mile and angle relationship information was transformed into a 51 x 99 matrix of road mileages. Only the latter matrix is presented here. An Iowa Agricultural Experiment Station publication [Warrack and Fletcher, 1967, in publication process] will detail the procedure and the results.

The potential plant locations, as previously defined, numbered 51. However, in model application some of these will be ruled out *a priori*. The computational cost burden increases very rapidly as the number of plants considered in the model increases. This practical consideration forced a paring of the number of potential plant sites to be considered. Consequently, the transportation matrix relevant to model application will be a submatrix of the 51 x 99 matrix.

A 50 x 99 road mileage transportation matrix is presented in Appendix D. This matrix omits Keokuk. For purposes of the present study, it was assumed that Fort Madison would always be chosen in deference to Keokuk. As a consequence, Appendix D was the starting point for the distribution cost analysis which follows.

D. Analysis of Transportation Costs

The Iowa transportation matrix which was developed contains a road mileage for every combination of potential plant site and node of county feed demand. The requirements of the model are to have every such combination expressed in terms of distribution costs where distribution costs are transportation costs plus selling costs. Cost per mile times miles will yield the desired transportation dollar figure for each combination.

1. Regulatory framework

Trucks must operate within the constraints set forth by Iowa law. Costs depend upon equipment used and the equipment alternatives must meet legal stipulations. The weight limitation is 73,280 pounds maximum. Tractor semi-trailers cannot exceed 55 feet in over-all length while double-bottoms cannot exceed 60 feet. The Iowa Motor Carrier Law [Iowa Commerce Commission, 1966], administered by the Iowa Commerce Commission, provides that motor carriers must obtain a permit to operate. The successful applicant must show financial ability, adequate insurance coverage and must file a table of rates (tariffs) to be charged for his services. There are some minor additional requirements. It is the concern of the Commission that all charges for services rendered shall be just, reasonable and non-discriminatory. Specifically, the law reads, "e) Table of rates.

All rates must be explicitly stated in cents or in dollars and cents, per 100 pounds, per mile, per hour, per ton of 2,000 pounds, per truck load (of stated amount), or other definable measure. Where rates are stated in amounts per package or bundle, definite specifications of the package or bundles must be shown and ambiguous terms, rates, descriptions or plans for determining charges will not be accepted. Tariffs containing tables of rates based on distances from point of origin to destination must show the mileages or indicate a definite method by which mileages should be determined."

In short, the carrier must file a tariff sheet with the Iowa Commerce Commission covering all the commodities he will haul. He is legally bound to follow the specifications of his filed tariff. However, there is the contract carrier exception -- constituted as a written agreement (on file with the Commission) between two parties for transportation of specified commodities. The rates in any such contract are the choice of the two concerned parties; but the carrier may not also be a common carrier for the specified commodities. Using feeds as an example, a carrier who wishes to haul this commodity would include a tariff set for feeds and be legally bound to follow it. An alternative would be for the carrier to enter into a contractual agreement(s) to haul feeds for one or more second parties; the contracts would be on file with the Commission and the carrier would be restricted to hauling feed only under contract.

2. Cost analysis

Two basic approaches can be used for truck transportation cost analysis. They will be referred to as the "cost approach" and the "revenue approach." Both were pursued. The former involves analyzing information based on cost surveys of trucking firms and feed companies that distribute their own products by truck. The "revenue approach," where revenue to the carrier is cost to the feed manufacturer or distributer, involves sampling actual tariffs.

a. Cost approach analysis and results Several studies have been conducted by the United States Department of Agriculture (USDA) analyzing motor truck costs. In each case, the basic data were obtained through sample surveys of truck operators. The results of these studies are of interest to the present study.

From a USDA sample of 28 larger farmer cooperatives, 20 usable questionnaires were obtained as a basis for truck cost analysis [Camp, 1964]. The study was national in scope. The selected cooperatives were those operating 25 plus trucks and who stated that 50 percent or more of their total truck mileage was "over-the-road."[1] The trucks, on the average, were driven 58,100 miles each year with an average of 178.4 miles per round trip. Most interviewees reported total operating costs in the 30.0 to 39.9 cents per mile range. The average was 36.0 cents. The cost breakdown of direct, overhead and

[1]"Over-the-road" was defined as hauls other than local pick-up and delivery and movements from fields to local concentration points.

indirect costs respectively contributed 25.6 (71.2 percent), 6.7 (18.5 percent) and 3.7 (10.3 percent) cents per mile. One additional point of interest is that only 21 percent of the trips had any backhaul.

Another USDA study focused on bulk-feed trucks [Camp, 1965]. Seven selected farmer cooperatives were analyzed. The bulk-truck sizes ranged from 6 to 21 tons. Apparently, bulk-feed trucks are more costly to own and operate than ordinary trucks. Direct costs averaged 37.6 cents per mile while overhead costs were 10.1 cents. The total is 47.7 cents per mile. Indirect costs were not analyzed. Backhauls were very low for these bulk-feed trucks.

Exempt for-hire haulers of exempt farm products were examined recently [Wright, 1964]. Regular and exempt haulers were analyzed separately but the results were similar. Results of cost estimates were given in terms of ranges. Nearly all were in the 21.3 to 33.7 cents per mile range. These estimates must be regarded as minimums inasmuch as costs of the operators' managerial and labor inputs were not included. One of the publications cited earlier [Camp, 1964] suggests the magnitude of these factors: drivers' wages were 13.0 cents per mile and indirect costs were 3.7 cents.

A somewhat dated study (using 1960 data) focused on costs of operating exempt for-hire motor carriers of agricultural commodities [Hunter, 1963]. The sample was from the DELMARVA region. The 25-truck-firm average cost per mile was found to be 28.8 cents. Gross revenue also was computed to be 30.5 cents per mile; the ratio of cost to revenue was 94 percent. This ratio result can be compared with findings of the 1963 Motor Carrier Survey -- total expense as a percent of total revenue for truck carriers of agricultural and other exempt products was 91 percent [Census of Transportation, 1966].

A USDA agricultural marketing economist presented a paper [Ulrey, ca. 1965] concerning Montana's transportation problems; in this paper a level of truck costs is suggested. In his analysis, Ulrey uses 35 cents per mile when discussing 20 ton loads and 30 cents for 15 ton loads. It is stated that these truck costs have been determined in the Department of Agriculture.

An Iowa State University survey of feed companies yielded some truck cost data for hauling feed. Usable data were obtained from 13 Iowa companies. Cost and mileage data were ascertained for the years 1962-63, 1963-64 and 1964-65. The results are summarized in Table 16.

Table 16. Summary of feed company truck costs per mile for Iowa

	1962-63	1963-64	1964-65
Range	22.00 - 39.20	25.00 - 47.40	25.00 - 47.10
Average	32.51	35.19	36.63

For 1964, an average figure of 35.91 cents per mile would be found by

$$(1/2)(35.19) + (1/2)(36.63).$$

b. Revenue approach analysis and results This approach to analyzing transportation costs involves determining actual charges by trucking firms for moving feed. These actual charges were found by sampling tariffs on file with the Iowa Commerce Commission. A cross-section of common carrier tariffs and contracts was examined. Costs per ton (or per hundredweight) were noted for each mileage category. As observed earlier, the truck operators are legally bound to the tariffs they have filed. What is revenue to the carrier is cost to the feed manufacturer or distributor.

A set of 15 tariffs was examined and data recorded. Since feed manufacturers generally are larger companies, it was felt that they would be in a favorable position to bargain with truckers who have feed. This seemed especially true inasmuch as the feed company is free to operate its own trucks if dissatisfied with bargains they can strike. Therefore, it did not seem reasonable to use simple averages to describe the feed companies' available alternatives for transporting feed. The negotiation process was simulated by taking the lowest 20 percent of the tariff sample. That is, for each mileage category the three lowest tariffs were selected and the average was found. The average cost per ton was computed; in addition, assuming 18 ton loads a cents per mile figure was computed for each mileage category. The results for zero to 500 miles are presented in Table 17.

In Table 17 mileage categories are incremented by 5 up to 100 miles and by 10 thereafter. For each mileage category the transportation cost in dollars per ton is given; the corresponding cents per running mile figure given assumes a load size of 18 tons.

Regressing cost per ton on miles indicated a linear relationship

$$CPT = 1.32 + 8.25 \text{ MILES}$$

TABLE 17. SELECTED SAMPLE OF PER TON COSTS, AVERAGE PER TON COST AND COST PER MILE FOR 18-TON LOADS

MILES	LOWEST	SECOND LOWEST	THIRD LOWEST	DOL/TON AVERAGE	CTS/MILE AVERAGE
5	1.00	1.40	1.40	1.27	228.00
10	1.00	1.60	1.70	1.43	129.00
15	1.00	1.70	1.80	1.50	90.00
20	1.20	1.70	2.00	1.63	73.50
25	1.50	1.70	2.00	1.73	62.40
30	1.44	2.00	2.40	1.95	58.40
35	1.68	2.00	2.60	2.09	53.83
40	1.92	2.24	2.60	2.25	50.70
45	2.16	2.52	2.60	2.43	48.53
50	2.40	2.60	2.70	2.57	46.20
55	2.20	2.97	3.00	2.72	44.56
60	2.40	3.10	3.12	2.87	43.10
65	2.60	3.20	3.38	3.06	42.37
70	2.80	3.30	3.50	3.20	41.14
75	3.00	3.40	3.57	3.32	39.88
80	3.20	3.50	3.64	3.45	38.77
85	3.40	3.60	3.72	3.57	37.84
90	3.60	3.70	3.79	3.70	36.97
95	3.80	3.80	3.87	3.82	36.22
100	3.90	3.95	4.00	3.95	35.55
110	4.08	4.10	4.18	4.12	33.71
120	4.21	4.30	4.56	4.36	32.67
130	4.33	4.50	4.94	4.59	31.78
140	4.45	4.70	5.04	4.73	30.41
150	4.58	4.85	5.10	4.84	29.06
160	4.70	5.00	5.30	5.00	28.12
170	4.83	5.15	5.40	5.13	27.14
180	4.96	5.30	5.50	5.25	26.27
190	5.09	5.45	5.70	5.41	25.64
200	5.21	5.60	5.80	5.54	24.91

TABLE 17 (CONTINUED)

MILES	LOWEST	SECOND LOWEST	THIRD LOWEST	DOL/TON AVERAGE	CTS/MILE AVERAGE
210	5.34	5.75	6.00	5.70	24.41
220	5.46	5.90	6.20	5.85	23.95
230	5.58	6.05	6.30	5.98	23.39
240	5.76	6.20	6.40	6.12	22.95
250	6.00	6.35	6.60	6.32	22.74
260	6.24	6.50	7.24	6.66	23.05
270	6.48	6.65	7.48	6.87	22.90
280	6.72	6.80	7.72	7.08	22.76
290	6.95	6.96	7.96	7.29	22.62
300	7.10	7.20	8.20	7.50	22.50
310	7.25	7.44	8.44	7.71	22.38
320	7.40	7.68	8.68	7.92	22.27
330	7.55	7.92	8.92	8.13	22.17
340	7.70	8.16	9.16	8.34	22.08
350	7.85	8.40	9.40	8.55	21.99
360	8.00	8.64	9.64	8.76	21.90
370	8.88	9.88	10.36	9.71	23.61
380	9.12	10.12	10.64	9.96	23.59
390	9.36	10.36	10.92	10.21	23.57
400	9.60	10.60	11.20	10.47	23.55
410	9.84	10.84	11.48	10.72	23.53
420	10.08	11.08	11.76	10.97	23.51
430	10.32	11.32	12.04	11.23	23.50
440	10.56	11.56	12.32	11.48	23.48
450	10.80	11.80	12.60	11.73	23.47
460	11.04	12.04	12.88	11.99	23.45
470	11.28	12.28	13.16	12.24	23.44
480	11.52	12.52	13.44	12.49	23.42
490	11.76	12.76	13.72	12.75	23.41
500	12.00	13.00	14.00	13.00	23.40

with a multiple R-square of 0.989. The nature of the cost per mile (assuming 18 ton loads) to miles relationship was a rectangular hyperbola configuration. Cost per mile declined steeply at first but became very flat after about 95 miles. A slight increase is noted at distances exceeding 360 miles. Perhaps truck operators "price themselves out" of the short-haul market.

c. Determination of transportation costs The procedure followed in determining truck transportation costs relied on results of both the cost and revenue approach analyses. The result is a 51 x 99 cost matrix where each element refers to total transportation cost of a potential plant site serving the feed demand of a county. For example, the transportation cost of a Sioux City plant serving the feed needs of Carroll County would be one element -- a similar figure lies in the matrix for each of the other 98 counties, and an analogous cost vector is presented for each of the other 50 potential plant sites.

Following the principle of choosing the least-cost method of moving feed, a cost per mile set of relationships were developed. The cost approach survey of truck costs resulted in calculating an average cents per mile cost of 35.91. It seems reasonable to expect the feed company to own and operate trucks as long as ownership costs per mile are less than those available by drayage. Conceptually, one can visualize drawing a constant cost per mile line (at 35.91 cents) on a graph and selecting that cost for all mileages that 35.91 cents is exceeded by the hyperbolic curve. The lines would cross between 97 and 98 miles.

The resulting configuration for beyond 97 miles was approximated by linear segments. The segment beyond 360 miles was so nearly constant that an average was taken (23.50 cents per mile) and used as constant.

Slope (change in cents per mile related to change in miles) was accounted for in three segments between 97 miles and 360 miles. The segments were: from 98 to 170 miles, between 170 and 250 and between 250 and 360 miles. In each case the change per mile in cents per mile was calculated. Thus the cost per mile adjustment could be made based upon the mileage position within the range of the corresponding segment. For example, between 170 and 250 miles the cost per mile falls from 27.14 to 22.74 cents; the per mile slope result is

$$\frac{1}{80}\,(27.14 - 22.74).$$

Then the slope result is multiplied by the number of miles beyond 170 and the resulting term subtracted from 27.14 cents per mile. The other two slope segments were handled analogously.

The adjusted cost per mile to mileage set of relationships, reflecting both approaches to cost analysis, is a set of five linear segments. From zero to 97 miles the cost is constant at 35.91 cents per mile; the constant cost from 360 to 500 miles is 23.50 cents. Negative slopes are computed for the other three segments. It is to be noted that costs per mile increase somewhat beyond 360 miles.

Each element of the 51 x 99 road mileage transportation matrix was multiplied by the appropriate cost per mile to obtain the cost per trip (or load of feed). Since the costs referred to running miles, the cost figures had to be doubled in order to obtain a 51 x 99 cost matrix where each element referred to cost per round trip (load of feed delivered) for a particular county and a particular potential plant location site.

The last step was to obtain a matrix where each element refers to the total transportation cost of a potential site serving the 1964 feed demand for a county. This was accomplished by finding how many 18 ton loads it takes to serve the feed tonnage demand of each county. Half a load (or more) was treated as a full load for transportation cost purposes while less than half a load was ignored. The result is a 51 x 99 total transportation cost matrix.

E. Selling Costs

The theoretical treatment of selling costs can be handled in conventional mathematical economics [Dorfman and Steiner, 1954]. In a context of profit maximization and efficiency criteria, sales effort (costs) should be undertaken up to the point where no further effort will increase profits. If resources constrain the firm to a sub-maximal profit level, sales expenses should be incurred to the point where each additional sales cost dollar yields the same amount of profit as each other profit-yielding activity -- in short, opportunity costs of profit-yielding activities are equalized.

Very little research has included the analysis of sales expenses. One aspect of a USDA feed industry cost study did consider sales expenses [Phillips, 1960]. This study analyzed one firm size under four types of organization: premix, concentrate, complete and retail-manufacturer feed production and distribution. A cross-section of the latter three types would be quite representative of the manufacturing organization for Iowa visualized in the present study.

The per ton sales expenses, found in the USDA study, were grouped into seven categories. The results are given in Table 18. The costs are based on 1955 data obtained by survey of actual feed firms in the Midwest. The firm size considered was that of 40,000 tons per year.

Table 18. Sales expenses per ton by type of expense for the feed manufacturing plants, by type of organization, 1955[a]

Expense item	Concentrate		Complete		Retail manufacturing	
	Av.	Range	Av.	Range	Av.	Range
			(dollars)			
1. Supervision	0.44	0.34-0.62	0.36	0-0.99	0	0-0
2. Salesmen	2.44	0.13-4.88	2.71	2.08-3.93	1.73	0.16-4.56
3. Travel and meetings	.51	.07-1.12	1.42	1.17-1.82	.15	.09-.19
4. Bad debts	.20	0-.60	.24	.19-.27	.27	0-.80
5. Telephone	.09	.07-.11	.13	0-.21	.19	0-.58
6. Advertising	.95	.08-1.39	1.08	.64-1.69	1.83	1.13-3.03
7. All others	.34	.09-.53	.29	.11-.47	.41	.02-.88
Total	4.77		6.16		4.59	

[a]Source: Phillips, 1960, p. 43.

The respective averages for concentrate, complete and retail-manufacturing operations were \$4.77, \$6.16 and \$4.59. The average of these three figures is $5.17. Nearly all of this feed was distributed to points within 100 miles of the manufacturing plant.

The cost level was adjusted upwards to reflect the general pattern of rising costs since 1955. A per ton sales expense differential of 16 percent was applied on the basis of changes in the consumer price index. Using the base period 1957-59 = 100, the consumer price index (all items) rose from 93.3 in 1955 to 108.1 in 1964; the rate of increase was 15.97 [Agricultural Statistics, 1966]. Hence, it seemed reasonable to take $6.00 per ton as a cost figure for sales expenses. This figure would apply to selling feeds up to about 100 miles from the location of the plant.

The level of selling costs per ton was related to distance. Per ton sales costs are expected to be higher as selling points are further removed from the feed manufacturing location. However, available evidence suggests that some level of sales expense is necessary even if strictly local markets are served. The USDA study cited earlier showed that retail-manufacturers sold nearly 60 percent of their output within 25 miles of the plant (96 percent within 50 miles) yet had sales expenses of $4.59 per ton; they spent a much higher percentage on advertising than did concentrate or complete feed manufacturers. Apparently selling expenditures in the feed industry are incurred as follows: a certain cost level for advertising, bad debts, salesmen, telephone and travel are necessary even though the sales area is small -- then, as the sales area expands, heavier expenditures for salesmen (and their expenses) begin to dominate selling costs.

In the absence of detailed selling cost data, an arbitrary cost-distance relationship was assumed. A linear relationship between average selling costs per ton and distance was established by using \$6.00 per ton at 100 miles distance and assuming the rate of cost change to be \$1.00 per ton for each 100 mile change in distance. This placed the intercept at \$5.00. Stated as a linear equation

$$Y = ax + b,$$

the numerical relation became

$$AC = 0.01\ X + 5.00$$

where AC = sales cost per ton and where X = miles distance between plant and selling point. For example, the per ton selling cost 300 miles removed from the plant location would be \$8.00.

The results of an Iowa State study [Scott, 1957], related to the above USDA study, underscores the importance of considering sales effort. A general linear program was applied to resource allocation and profit maximization within the individual feed manufacturing firm. The solution indicated that by far the most productive activity in the company was field sales effort. The resultant recommendation was that sales effort, in the form of salesmen hours spent with customers, should be increased if profits are to be maximized.

F. Feed Manufacturing Costs

Manufacturing costs represent 6 to 10 percent of total costs faced by the feed industry [Schoeff, 1961, p. 17]. Only ingredient costs and transportation costs are more important. Labor accounts for about half the cost of manufacturing a ton of feed.

The feed industry is strongly aware of the importance of cost efficiency in the manufacturing process. The industry sponsors an annual "Feed Production School" where various aspects of production efficiency are studied. The usual nature of industry studies has been to examine and suggest cost standards -- with the primary focus being on labor. Actual cost data have seldom resulted. Nevertheless, the individual firms and their associations have been cooperative with researchers.

At the outset it may be useful to review an industry approach to costs. The following cost classification is from an industry publication [Phillips, 1961]. Fixed costs include all those expenses not related to how much tonnage goes through the plant:

i) costs of owning the plant -- depreciation, interest, insurance and property taxes on facilities and equipment;

ii) overhead costs -- salaries of management and office workers, and general administrative and office expenses;

iii) fixed operating expenses -- supervisory labor, heat and lights, and minimum power charges; and

iv) fixed maintenance costs -- fixed maintenance labor and contractual service charges.

Variable costs vary in (more or less) direct proportion to tonnage variations:

i) labor costs other than for managerial, supervisory and general office personnel;

ii) fuel and power costs;

iii) repairs to facilities and equipment;

iv) plant and other supplies; and

v) direct sales promotion and delivery expenses.

Available feed manufacturing cost studies have followed one of two basic approaches: economic-engineering, or statistical. Most have used the former approach. It involves obtaining basic information and coefficients from feed manufacturers and applying industry and engineering standards to "build" a manufacturing unit and compute its costs. The statistical approach analyzes cost data by sample surveying of company cost records. Some of the problems inherent in each approach will be noted as various studies are reviewed. One general distinction is crucial: while the statistical approach seeks a positive description of actual feed manufacturing costs, the objective of economic-engineering studies is to establish attainable normative cost standards.

The objective of this section is to illustrate the development of long-run average costs for manufacturing feeds. This development will include both single- and double-shift operations; a range of plant sizes will be examined for each. A synthesis of several feed manufacturing cost studies is undertaken. The final result will be a long-run average cost function for single-shift operations and another for double-shift operations. Then the attendant long-run total cost functions can be derived.

Nearly all feed industry studies are based on an assumption of operating 260 days per year. This research will adhere to this same assumption throughout.

The cost analysis of the present study focuses on manufacturing as distinct from custom-milling or retail operations. Custom-milling costs have been studied elsewhere [Tamashumas, 1959] as have over-all feed retail operations [Streeter, et al., 1965].

1. USDA cost center studies

The United States Department of Agriculture has conducted a series of feed manufacturing cost analyses on industry-defined cost centers. The industry has defined seven cost centers.

Ingredient receiving: The cost center begins as the railroad car or truck is located at the unloading dock and includes receiving, storing and handling to the first point of rest. The center ends as materials are located at the point of rest either in holding bins or in the receiving warehouse.

Grain processing: The cost center begins with the grain to be processed (resting in grain storage bins). The center includes all work entailed in grinding, crimping and cracking operations and the movement of grain to and from grain processing equipment -- ending with the processed grain being held either in mixing bins or in ingredient storage bins.

Mixing: The cost center begins with the point of storage of ingredients to be mixed and includes all material movements, weighing, opening of bags, dumping and the actual mixing operation. Addition of liquids is included here. The last operation is the movement of all mixed feed into bins or to the scales for packing.

Pelleting: The cost center begins with mixed feeds held in bins over pellet machines and ends as pellets or crumbles are moved into holding bins either for packing or bulk delivery. All work necessary to change dies and operate feeder, extruder, cooler, scalper, duster and crumble roll equipment is included.

Packing: The cost center involves all operations related to obtaining packing equipment as well as weighing and packing.

Warehousing: The cost center begins with bagged or bulk feed which is ready to be moved through the warehouse to holding areas or bins. The loading of the finished product into facilities for distribution is included; the center ends when the feed is loaded and is ready for transport.

Maintenance: The cost center includes all regular and preventative maintenance work throughout the mill. Major building repairs and highway truck maintenance are not included. In many cost studies, the maintenance cost center is dissolved by including maintenance requirements in each of the previous six cost centers.

Two major points are to be noted in relation to using the cost center classification as a basis for cost analysis. Cost allocations for buildings and land are difficult to make on the basis of cost centers. Second, the tonnage moving through each cost center will not be the same; as an example, 100 tons of finished feed output would require that fewer than 100 tons of grain be processed.

In a USDA study series the maintenance cost center was subsumed into the other six. These cost studies have some normative connotation inasmuch as the economic-engineering approach was used and the cooperating feed manufacturers had attended at least one feed production school session. Four of the six reports were based on 80 and 200 ton per day mile sizes. Double shifts also were considered. Each report details labor and equipment requirements, investment and operating costs and standards for labor and equipment usage. The USDA researchers believe the cost standards used are attainable by nearly all plant managers.

The six cost center studies will be reviewed in turn. Each contains a cost center flow diagram -- useful for illustrating the functions performed in each cost center. A summary table will collect the cost results. Since these studies do not relate to the same time period, an adjustment in labor costs is necessary. Adjusted cost results will be indicated in the same table.

a. Ingredient receiving costs   Costs of receiving and handling feed ingredients were studied for 80 and 200 ton per day plant outputs [Vosloh, 1965a]. It was assumed that 80 percent of incoming ingredients would be bulk with the remainder in bags.

The receiving center should handle about the same tonnage per day as the quantity of mixed feed manufactured. Labor was classified as production and supervisory and industry performance standards were assumed; the production labor wage rate assumed was $2.05 while $2.50 was used for supervisory labor. For maintenance workers, $2.35 per hour was assumed. An increment of 10 cents per hour was added for all labor working night shift. The straight-line method was used for depreciation while 3 percent interest was charged each year on total capital investment in equipment.

Operating two shifts per day allows fixed costs to be spread over a greater output volume. Variable costs, primarily labor (paid 10 cents per hour more for night shift), became a greater part of total cost. By operating two 8-hour shifts, per ton costs are reduced from 64 cents to 50 cents for the smaller plant and from 50 cents to 41 cents in the larger. One recommendation of the study was that plant managers consider operating more than one shift as an alternative to more automation.

b. Processing costs Particle reduction is an important operation. An important assumption was that 60 percent of a feed plant's output is routed through the processing center for grinding, crimping or cracking before the mixing operation. The respective quantities to be processed are 45 and 120 tons [Vosloh, 1965b].

Day-shift operating costs were handled in a manner exactly analogous to the receiving center. The same wage rates were used. The resulting costs were 85 cents per ton of material processed by the smaller plant and 61 cents for the larger. The second (night) shift was not dealt with specifically but can be approximated by halving the interest and depreciation costs (fixed costs) per ton and allowing for 10 cents more per hour for night-shift workers. One more adjustment was necessary since it was desired to state cost of processing in terms of the plant's total feed output; the cost per ton of feed output is 60 percent of the cost per ton of ingredient materials actually processed.

c. Mixing costs   As in the two preceding USDA studies, industry-established standards for labor and equipment were followed in studying mixing costs [Vosloh, 1962]. Wage rates are somewhat low because the study was completed a few years ago. Depreciation and interest were charged as before.

The results show that per ton mixing costs can be reduced by operating larger plants and/or more than one shift per day. On a one-shift basis, the 200 ton plant (52,000 tons per year) mixes for 63 cents while the 80 ton plant (20,800 tons per year) cost is 80 cents per ton. The respective double-shift mixing cost results are 55 cents and 70 cents per ton.

d. Packing costs   The fourth USDA report which followed the 80 ton and 200 ton per day size format dealt with packing mixed feeds [Vosloh, 1964]. An assumption of the packing cost center was that plants package 80 percent of the mixed feed production while the other 20 percent is bulk mixed feed. Labor wage rates used for production, supervisors and maintenance respectively were $1.86, $2.50 and $2.25 per hour for day shift and a 10 cent increment for night. Equipment, depreciation and interest were handled as before.

The daily tonnage packed in the respective model mills would be 64 and 160 tons per shift. The cost results show that it costs less per ton to package feeds in the larger plant as compared to the smaller; moreover, per ton costs are lessened when more than one shift is operated. An adjustment was made to permit stating cost per ton of total feed rather than per ton of feed packaged.

Based on 64 tons per day, the single-shift unit cost was 39.3 cents; the double-shift unit cost was 36.6. In the larger model, these costs per ton packaged were 29.8 and 27.1 cents. Eighty percent of each cost figure would reflect cost per ton of plant feed output. These are 31.5, 29.3, 23.8 and 21.7 cents respectively.

e. Pelleting costs Pelleting of feed is a process by which premixed dry feeds (mash) are formed into relatively hard pellets of various sizes. The pellet form offers some advantages over mash: increased livestock gains, less farmer labor, less waste, less dust and greater density allowing greater tonnage for a given space. The USDA study reviewed here examines a pelleting model for a small feed manufacturing plant and gives cursory consideration to a larger one [Vosloh, 1961].

An annual pelleting capacity of 7,800 tons (30 tons per day) was assumed for detailed cost analysis. Such a size might "harmonize" quite well with an 80 ton feed manufacturing model mill.

Equipment, depreciation and interest costs were handled as before. Production labor was assumed to be paid $2.07 per hour while supervisory labor was charged at $715 per year or 9 cents per ton. The report concluded that a larger pelleting cost center (say twice as large) would require twice the equipment expenditure but only the same amount of labor. Hence, per ton labor costs would be halved.

Only one-shift operations were considered in the report. An adaptation of the cost results allowed an approximation of two-shift costs; labor costs were more than doubled while depreciation and interest costs were halved. The adapted results are: $2.32 per ton pelleted ($0.87 per ton of feed output) in the small single-shift model, and $2.19 and $0.82 respectively for small double-shift model; $2.11 per ton pelleted ($0.79 per ton of feed output) in the large single-shift model, and $1.96 and $0.74 respectively for the large double-shift operation. The two pelleting models are assumed to correspond roughly with the two model mill sizes (80 and 200 ton) studied by USDA researchers. The cost results were based on tonnages pelleted so an adjustment was necessary if costs were to be stated in terms of total plant feed output.

f. Warehousing costs   The emphasis in each of two USDA studies was labor time and consequent costs [Askew, et al., 1957; and Brensike, 1958]. In both, the results represent analysis of a case study of six plants having a daily volume of 100 tons.

USDA researchers found that the total warehouse costs per ton of feed shipped was $1.58 with 69 percent of total warehouse operating costs accounted for by labor. The cost per ton of feed produced was $1.47; some feed bypasses the warehouse.

Warehousing cost standards developed by the industry indicate that an 80 ton per day plant should need only 0.309 man-hours per ton while a 200 ton plant should require 0.264 hours of labor per ton. At $2.30 per hour these respective labor costs would be 71 and 61 cents -- far less than the actual cost results indicated above. If labor costs represent 69 percent of the total warehousing costs, the respective total warehouse costs would be $1.03 and $0.88 per ton.

A major conclusion of the warehouse cost studies was that labor efficiency generally could be improved by about one-third.

g. Summary of results The numerical results of the six USDA cost center studies are reported in Table 19. In addition, a column of updated results accompanies each column of reported results. Labor costs have tended to rise over the years so most of the reports had to be updated with reference to labor costs.

Labor costs were adjusted to levels indicated by Bureau of Labor Statistics data on hourly earnings. For the "prepared feeds" industry (SIC 2042) the national 1964 figure was $2.03 [Bureau of Labor Statistics, 1964]. On a state basis, information is available to only three digits (SIC 204 for grain mill products) -- this figure is $2.77 for Iowa as compared to a national figure of $2.44 [Bureau of Labor Statistics, 1964, p. 411]. An Iowa SIC 2042 figure can be obtained by ratio estimation; the result is $2.30 per hour for Iowa production workers in the feed manufacturing industry. Supervisor's wage rate is assumed at $2.80 per hour. A 15 cent increment is assumed for the night shift. All of these figures would include fringe benefits worth roughly 40 cents per hour.

The USDA cost center study results are used for two purposes in the present study. Certain components of the over-all cost synthesis will rely on the USDA results. Second, the results are useful as an absolute cost level benchmark for comparative purposes.

Table 19. USDA cost center results and updating adjustments, dollars per ton

	One shift				Two shifts			
	80 ton (20800)		200 ton (52000)		80 ton (41600)		200 ton (104000)	
Cost center	Reported results	Updated results	Reported results	Updated results	Reported results	Updated results	Reported results	Updated results
Ingredient receiving	.64	.67	.50	.53	.50	.53	.41	.44
Processing	.51	.52	.37	.37	.46	.46	.32	.32
Mixing	.80	.87	.63	.67	.70	.77	.55	.59
Packing	.32	.36	.24	.27	.29	.34	.22	.26
Pelleting	.87	.90	.79	.81	.82	.86	.74	.75
Warehousing[a]	1.03	1.03	.88	.88	1.03	1.03	.88	.88
Total cost		4.35		3.53		3.99		3.24

[a]Constant per ton costs with increasing shifts implicitly assumes that additional labor costs are exactly offset by decreasing fixed costs per ton.

2. New England cost study

A comprehensive study on economies of scale in feed manufacturing was undertaken at the University of New Hampshire with the University of Massachusetts and the USDA cooperating [Burbee, et al., 1965]. Poultry feeds were emphasized in this economic-engineering cost study. Costs for eight model mills were developed. The mill volumes were: 20.9, 41.8, 62.7, 83.6, 125.4, 174.2, 261.3 and 348.4 tons per day.[1] The yearly volumes range from 5,434 to 90,577 tons. The cost sources were grouped into six classes: labor inputs and costs, investment and costs for feed manufacturing facilities, ownership costs, administrative and supervisory personnel costs, utility costs and other costs.

Most feed manufacturing cost studies have tended to emphasize labor costs and compare labor requirements to some standard as a proxy for comparing plant production efficiency. In the New England study the labor force consisted of production workers who perform the several manufacturing processes plus maintenance and general repairs. The man-hours per ton ranged from 1.00 to 0.16 between the smallest and largest of the eight model mills. The per hour wage rate for production and maintenance personnel respectively was $1.85 plus 37 cents fringe benefits and $2.00 plus 40 cents fringe benefits. Labor combined cost per ton, from smallest to largest,

[1]The uneven tonnage sizes result from coordinating model mill sizes with poultry processing sizes -- thus facilitating the over-all study of varying-sized integrated operations.

ranged from $2.26 to 36 cents. Variable costs such as equipment repair and service, mill supplies, inventory (interest on investment and insurance) and shrinkage of 1/4 of 1 percent (loss of moisture and losses of ingredients due to unloading, handling, storing, loading, etc.) were charged under "other costs."

Investment for feed manufacturing facilities included equipment and the physical plant (mill and storage building facilities). Equipment items required were synthesized from input-output relationships and manufacturer's equipment specifications. These items are detailed in Appendix C of the original publication [Burbee, et al., 1965, p. 56]. Delivered equipment costs and installation costs were determined. Physical plant costs were treated in a similar manner. Land requirement estimates were obtained from physical layout drawings and charged at $5,000 per acre. Two major ownership costs were depreciation (due to time, wear and obsolescence on the physical plant and equipment facilities) and interest on investment (6 percent of equipment, buildings and land values). Other ownership costs were property taxes, insurance and fixed maintenance costs (to keep buildings, equipment and facilities in operating condition).

A number of administrative and supervisory functions must be performed to insure accurate records, coordination and production control. These specific functions include management, ingredient purchasing, nutrition and ration formulation, quality control, bookkeeping and supervision of personnel. There are some miscellaneous fixed costs accounted for in the study; these are costs such as registration and analysis fees, audit and legal fees, management travel costs and so forth.

The total costs per ton are summarized in Table 20. The total variable cost per ton declines steadily in the size progression from smallest to largest. A discontinuity between plant sizes 3 and 4 exists for total fixed costs per ton. This discontinuity exists because substantial changes in manufacturing technology are incorporated at that size level. However, the total cost per ton decreases monotonically from the smallest to the largest model mill.

The results of the New England study will be supplemented with other cost study results, especially the USDA cost center series, as the over-all cost analysis synthesis is executed. Certain wage rate adjustments also will be necessary.

3. Other cost studies

One comprehensive USDA study examined feed company costs for four types of marketing organizations [Phillips, 1960]. The study was statistical in nature and analyzed procuring, manufacturing and distributing costs for mixed feeds. The geographic focus was Midwestern. No economies of scale were considered since 40,000 tons annual volume was assumed.

The analysis included two types of costs usually ignored: ingredient procurement and sales expenses. Detailed purchasing costs could be obtained only for "concentrate plants"; actual costs were 42 cents per ton whereas 35 cents was budgeted. Sales expenses

Table 20. Summary of costs per ton for operating eight model mills at capacity, New England study[a]

Item	Mills 1 5,434	2 10,868	3 16,302	4 21,739	5 32,609	6 45,287	7 67,933	8 90,577
	(dollars per ton)							
1. Labor								
a. Production	1.96	1.57	1.42	.85	.62	.38	.29	.26
b. Maintenance	.30	.23	.20	.20	.15	.13	.11	.11
2. Utilities	.82	.77	.75	.73	.77	.69	.70	.67
3. Equipment repairs and services	.63	.51	.44	.56	.43	.42	.40	.36
4. Mill supplies	.09	.09	.09	.09	.09	.09	.09	.09
5. Inventory costs	.08	.08	.08	.08	.08	.08	.08	.08
6. Shrink	.17	.17	.17	.17	.17	.17	.17	.17
Total variable cost	4.04	3.42	3.15	2.67	2.32	1.96	1.83	1.74
7. Ownership costs	2.78	2.18	1.90	2.34	1.85	1.76	1.62	1.50
8. Administrative and supervisory	1.44	1.16	.98	.91	.86	.76	.66	.60
9. Miscellaneous	.34	.29	.26	.24	.21	.19	.18	.17
Total fixed cost	4.55	3.62	3.14	3.50	2.91	2.71	2.47	2.27
Total cost	8.59	7.05	6.29	6.17	5.23	4.68	4.30	4.01

[a]Source: Burbee, _et al._, 1965, p. 29.

(including advertising) for three types of marketing organizations[1] averaged $5.17 per ton although the average budgeted level was $6.03; this cost category would be expected to vary with market area covered. These two cost category results are implicated into the over-all cost results.

In a statistical cost analysis done at Iowa State University, regression analysis was used to examine feed manufacturing costs [Phillips, 1956]. It was noted that a simple regression of cost on volume is an inappropriate estimate of the long-run cost function because the position of each plant on its short-run cost function is not considered. Phillips added a capacity utilization variable in order to adjust observations on the short-run cost function to its point of tangency with the long-run cost function. The long-run cost volume relationship exhibited economies of scale.

The context of his study is the formal treatment of statistical cost analysis by J. Johnston [Johnston, 1960]. Considerable doubt has been shed on the empirical validity of Phillips' results [Stollsteimer, et al., 1961].

A North Dakota study of feed manufacturing costs used 30,100 and 200 ton per day rated-capacity model plants [Austin and Nelson, 1966]. However, none of its cost results are utilized in the present study's cost synthesis.

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[1] A cross-section of three of the types (excluding premix) would represent the sort of feed manufacturing operation envisaged in the present study.

4. Syntheses of volume-cost relationships

In order to fulfill the primary research objective of the present study, the sub-objective of manufacturing cost determination had to be accomplished. A set of estimates comprising the long-run average cost function (LRAC) was needed. The LRAC was sought for both single- and double-shift operations. Then the corresponding long-run total cost functions (LRTC) could be derived. The long-run total manufacturing cost function is a major component in the long-run spatial model.

a. Single-shift synthesis The New England study, reviewed in detail earlier, was used as a benchmark for synthesizing a cost-volume relationship which would be representative of the Iowa feed manufacturing situation. There were several ways in which the New England study results had to be adjusted or supplemented. The study referred to bulk feeds exclusively; since packaged feeds are very important in Iowa, a packing cost center had to be added. Wage rates had to be adjusted. Supplemental warehouse labor and supervision had to be added under the thesis that bagged feeds require more warehousing labor than bulk feeds. Finally, an ingredient procurement cost category was implicated.

A total of 14 manufacturing and manufacturing-related cost categories were developed -- see Table 21. Table 21 consists of Table 20 addended by the aforementioned additions and adjustments.

The labor cost adjustment was slight -- from \$2.22 (\$1.85 plus 37 cents fringes) to \$2.30 per hour. As an example, the labor cost differential for model size number 4 was only 4 cents per ton --

Table 21. Single-shift long-run average costs per ton for eight model plant sizes

Model number	1	2	3	4	5	6	7	8
Daily tonnage	20.9	41.8	62.7	83.6	125.4	174.2	261.3	348.4
Yearly tonnage	5,434	10,868	16,302	21,739	32,609	45,287	67,993	90,577
	(dollars per ton)							
A. Variable costs								
1. Labor -- production and maintenance	2.26	1.80	1.62	1.05	.77	.51	.40	.37
2. Utilities	.82	.77	.75	.73	.77	.69	.70	.67
3. Equipment repairs and services	.63	.51	.44	.56	.43	.42	.40	.36
4. Mill supplies	.09	.09	.09	.09	.09	.09	.09	.09
5. Inventory costs	.08	.08	.08	.08	.08	.08	.08	.08
6. Shrink	.17	.17	.17	.17	.17	.17	.17	.17
Variable cost subtotal[a]	4.04	3.42	3.15	2.67	2.32	1.96	1.83	1.74
B. Fixed costs								
1. Ownership costs	2.78	2.18	1.90	2.34	1.85	1.76	1.62	1.50
2. Administrative and supervisory	1.44	1.16	.98	.91	.86	.76	.66	.60
3. Miscellaneous	.34	.29	.26	.24	.21	.19	.18	.17
Fixed cost subtotal[a]	4.55	3.62	3.14	3.50	2.91	2.71	2.47	2.27
C. Added costs								
1. Labor cost differential	.08	.07	.06	.04	.03	.02	.01	.01
2. Packing cost center	.41	.39	.38	.36	.33	.29	.25	.18
3. Additional warehouse labor	1.34	1.34	.98	.62	.62	.58	.53	.53
4. Additional warehouse supervision	.09	.09	.07	.06	.06	.06	.06	.06
5. Ingredient procurement	.42	.42	.42	.42	.42	.42	.42	.42
Added cost subtotal	2.34	2.31	1.91	1.50	1.46	1.37	1.27	1.20
Grand cost per ton total	10.93	9.36	8.20	7.67	6.69	6.05	5.57	5.21

[a]May not add because of rounding.

from \$1.05 to a total of \$1.09. The labor cost adjustments are reflected in row C.1 in Table 21.

The addition which represented the packing cost center was based on USDA results. The results in C.2 were obtained by linear extrapolation of updated packing costs from Table 19.

The adjustment of warehousing costs is more difficult since some of these costs have been included previously. In the study by Burbee, et al., warehousing costs were parceled into the mixing and pelleting activities because the output is bulk in form; in addition, the loading of feed was considered a distribution activity whereas USDA studies regard the warehousing function as inclusive of loading.

It seems reasonable to assume that equipment and facility costs would differ little according to the bulk vs. bagged relationship in warehousing. But considerably more labor is needed when bagged feeds must be warehoused. A study cited earlier noted that 69 percent of total warehousing costs were labor costs. The adjustment was made assuming that 60 of the 69 percent (0.87) which is labor cost does not appear in the typical bulk feed manufacturing plant. Therefore, 87 percent of the industry standard for labor in warehousing was added. According to industry standards, 0.671, 0.309 and 0.264 hours per ton should be required for small (7,500 to 10,000 tons annually), medium (25,000 to 35,000 tons annually) and large plants (50,000 to 75,000 tons annually) [Brensike, 1958, p. 2]. The costs of this additional labor are reflected in row C.3 of Table 21.

With additional labor more supervision is necessary. The computed cost increments yield row C.4. Foreman time industry standards for small, medium and large volumes are 0.133, 0.80 and 0.80 hours per ton respectively. An additional industry standard is that about one-third of foreman time pertains to supervision of warehouse personnel. It is assumed that one-quarter[1] of the industry standard was needed for additional warehouse supervision.

Ingredient procurement costs were entered at a constant level for each plant size. Two considerations could have caused costs to differ but did not. In the New England study taxes were charged at $5.00 per hundred dollars on 50 percent of total mill investment; this corresponded exactly with the representative Iowa situation of 100 mills on 25 percent of market [Iowa State Tax Commission, 1964]. Actually, it would take a rather dramatic tax cost differential to affect per ton costs. New England land was valued at $5,000 per plant site acre. Even though Iowa land would be much less expensive (one-half or less), the lowering of per ton cost was inconsequential -- less than 1 cent per ton.

How realistic is the LRAC curve suggested by Table 21? As a partial test, a subset of the synthesized cost results was compared to the USDA results presented in Table 19. The cost subset is the content of Table 22. Only single-shifts of the two USDA sizes are compared.

---

[1]One-quarter is used instead of one-third because some supervision for warehouse labor has already been taken into account.

The first four entries are corresponding entries from Table 21. However, the last two entries are fractions of the corresponding Table 21 entries. The synthesized cost results include the ownership of more physical facilities than the USDA cost center studies --

Table 22. Comparative subset of synthesized cost data, two plant sizes

Cost item	80 ton	200 ton
	(dollars per ton)	
Labor -- production and maintenance	1.09	.47
Utilities	.73	.70
Packing	.36	.27
Warehousing	.62	.53
Ownership	1.25	.92
Administration and supervision	.29	.24
Total cost per ton	4.34	3.13

mainly buildings and land. Fewer operational activities are within the scope of the USDA study series so fewer administrative and supervisory costs were applicable.

The ownership costs relevant for the USDA comparison are those for equipment exclusive of land and the physical plant. For the 80 ton plant, 53.5 percent of the total investment was for equipment while the 200 ton equipment percentage was 54.3. The respective computations become:

(.535)($2.34) = $1.25 and

(.543)($1.69) = $0.92

where $1.69 is the average of entries 6 and 7 in row B.1 of Table 21.

The portion of administrative and supervisory costs relating to the production cost centers needs to be allocated. For both sizes the synthesized cost results show that 25 percent of total administrative personnel costs are foreman costs. Consequently, the respective computations become:

(.25)($0.91) = $0.23 and

(.25)($0.71) = $0.18

where $0.71 is the average of entries 6 and 7 in row B.2 of Table 21. One more step is needed: add the warehouse supervision cost differential of row C.4. The respective estimates for the two sizes become $0.29 and $0.24 -- the relevant entries in Table 22.

Compare Table 22 with the relevant entries in Table 19. The results are reasonably comparable although the former are somewhat lower than the latter. An important indication of economies of scale is implicit in each.

Figure 12 illustrates the synthesized long-run average cost function. Eight observations representing the total manufacturing cost function are depicted in Figure 13 along with the regression line. The total cost function apparently is linear. The linear equation is

Total Costs = 53202.5 + 4.74084 Volume

with an R^2 of 0.994.

b. Double-shift synthesis Numerous cost study interpretations have suggested that feed manufacturing plants be operated more than one shift per day. These recommendations are based on cost analyses.

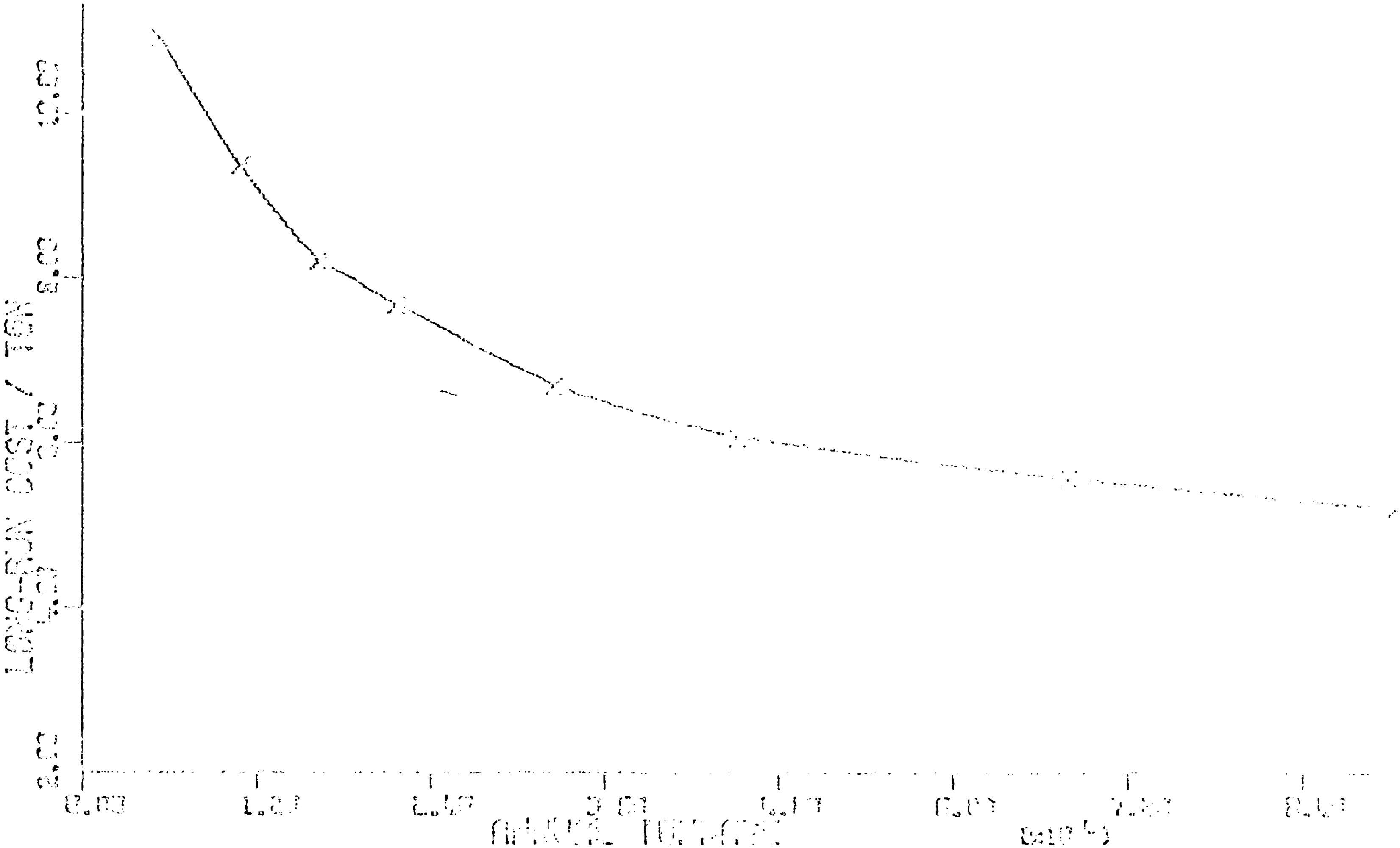

Figure 12. Long-run average cost function, single-shift synthesis

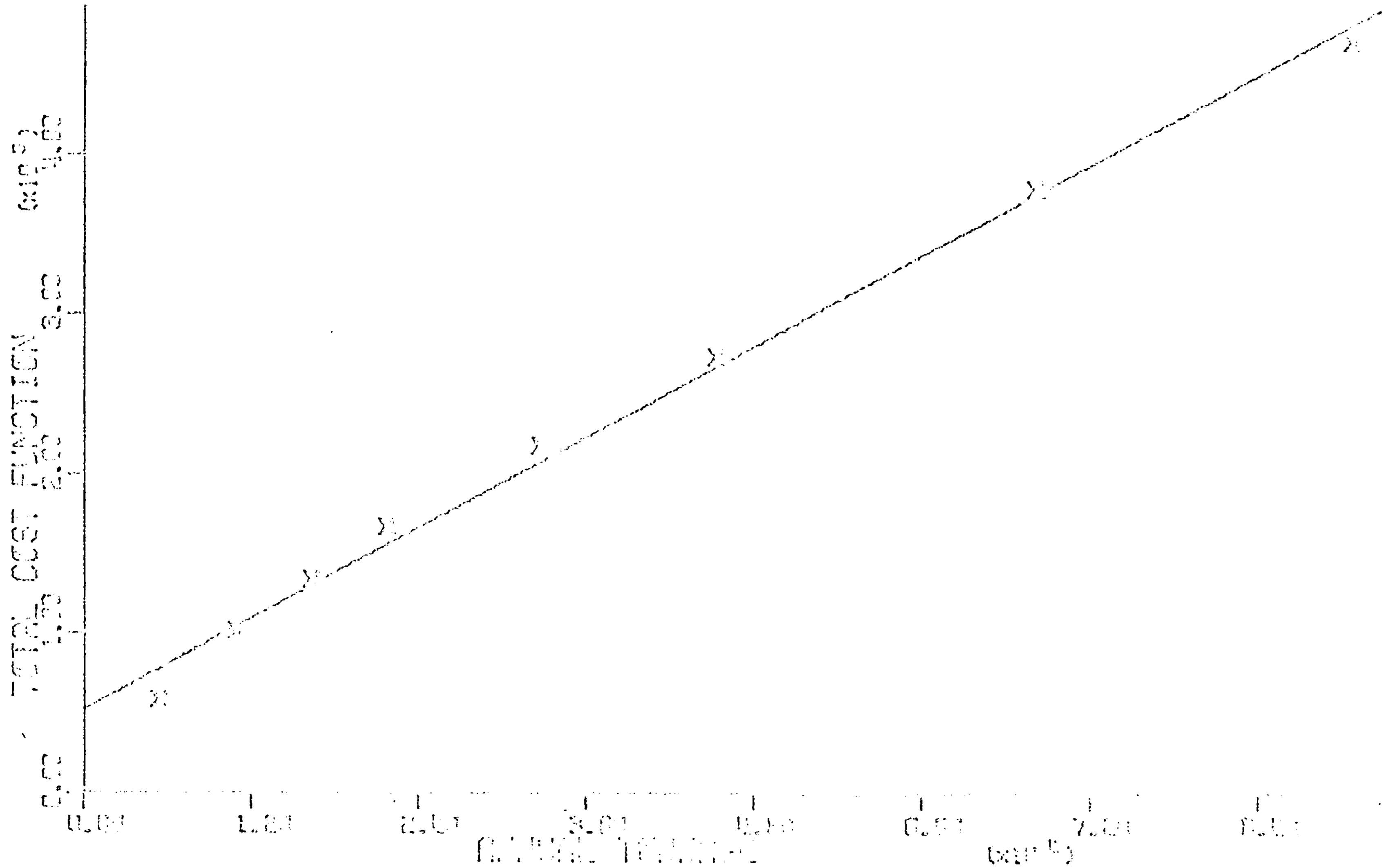

Figure 13. Long-run total cost function, single-shift synthesis

The synthesized single-shift cost estimates of the present study were used as a basis for obtaining double-shift cost estimates.

In deriving double-shift estimates, single-shift estimates were handled in four basic ways depending upon the nature of the cost element. As output doubles (per 24-hour day or per year), some per ton cost elements would remain invariant while some fixed cost elements would be halved. Other cost elements would increase per ton. Still other costs per ton would decrease but the decrease would be less than half.

Costs per ton related to utilities, equipment repairs and services, mill supplies, inventory, shrink and ingredient procurement would not be expected to vary with the number of shifts operated.

The variable per ton costs which would be expected to increase are those related to labor and labor supervision. A 15 cent increment for the night shift was assumed; the respective wage rates thus become $2.45 and $2.95 per hour. The labor cost increment for night-shift work had impact on four Table 21 cost categories: variable labor costs (A.1), labor cost differential (c.1), additional warehouse labor (C.3) and additional warehouse supervision (C.4). Using computational procedures analogous to developing single-shift estimates, average costs for the night shift were developed. The next step was to find over-all average costs by averaging the single-shift and double-shift results. Take the variable labor cost of the smallest plant as an example: the single-shift cost was $2.26 per ton while the double-shift cost was $2.42, the combined average cost per ton is \$2.34 or (1/2)(2.26 + 2.42). The plant costs of operating one day shift and one night shift were thereby represented.

Table 23 presents the cost results for a two-shift operation for eight model plant sizes. The cost entries correspond precisely with those of Table 21.

Some fixed costs per ton could be halved by operating 16 hours per day instead of eight. These would include such cost sources as mill building, office, land and executive personnel. However, some costs regarded as fixed for rate of output would not be fixed as hours of operation are varied -- these are costs related to ingredient and output materials: warehouse, grain storage and finished-feed holding facilities. For these three physical plant facilities, it was assumed that double investment was needed to permit double production through double-shifting.

Depreciation is loss of value due to time, obsolescence and wear. Albeit nearly all cost studies halve equipment costs when considering two shifts, it seems that equipment will wear more when operated 16 rather than 8 hours per day. *A fortiori* time and obsolescence, relative to wear, would become less important sources of depreciation cost. It was assumed that equipment life was shortened 25 percent by the added stress and wear of the second shift. The computational consequence was that fixed equipment costs per ton of output were cut by one-quarter rather than one-half by operating two shifts. This alternative assumption regarding equipment had an important effect on costs since equipment represented over half the total investment in each model plant size.

Table 23. Over-all single- and double-shift average costs per ton for eight model plant sizes

Model number	1	2	3	4	5	6	7	8
Daily tonnage	41.8	83.6	125.4	167.2	250.8	348.4	522.6	696.8
Yearly tonnage	10,868	21,736	32,604	43,478	65,218	90,577	135,986	181,154
	(dollars per ton)							
A. Variable costs								
1. Labor -- production and maintenance	2.34	1.87	1.67	1.09	0.80	0.53	0.42	0.39
2. Utilities	.82	.77	.75	.73	.77	.69	.70	.67
3. Equipment repairs and services	.63	.51	.44	.56	.43	.42	.40	.36
4. Mill supplies	.09	.09	.09	.09	.09	.09	.09	.09
5. Inventory costs	.08	.08	.08	.08	.08	.08	.08	.08
6. Shrink	.17	.17	.17	.17	.17	.17	.17	.17
Variable cost subtotal	4.13	3.49	3.20	2.72	2.34	1.98	1.86	1.76
B. Fixed costs								
1. Ownership costs	1.61	1.26	1.09	1.35	1.06	1.01	.94	.86
2. Administrative and supervisory	.72	.58	.49	.46	.43	.38	.33	.30
3. Miscellaneous	.17	.15	.13	.12	.11	.10	.09	.09
Fixed cost subtotal	2.50	1.99	1.71	1.93	1.60	1.59	1.37	1.25
C. Added costs								
1. Labor cost differential	.16	.13	.12	.08	.06	.04	.03	.03
2. Packing cost center	.40	.38	.37	.35	.32	.28	.25	.18
3. Additional warehouse labor	1.43	1.43	1.04	.66	.66	.62	.56	.56
4. Additional warehouse supervision	.10	.10	.07	.06	.06	.06	.06	.06
5. Ingredient procurement	.42	.42	.42	.42	.42	.42	.42	.42
Added cost subtotal	2.51	2.46	2.02	1.57	1.52	1.42	1.32	1.25
Grand cost per ton total	9.14	7.94	6.93	6.22	5.46	4.89	4.55	4.26

The composite of these fixed cost considerations is in ownership costs -- presented in row B.1 of Table 23. The magnitude of these entries exceeds half the magnitude of the corresponding entries in Table 21. As before, the over-all average cost figures were obtained by averaging the single-shift and double-shift cost magnitudes.

Figure 14 illustrates the combined long-run average manufacturing cost function. The derived total manufacturing cost function is depicted in Figure 15; it is linear in nature with the equation

$$\text{Total Costs} = 90064.25 + 3.84544 \text{ Volume}$$

and an R^2 of 0.995.

The long-run average cost curves for single- and double-shift feed manufacturing operations are compared in Figure 16. The single-shift curve is the one corresponding to the narrower volume range. For volumes greater than 50,000 tons annually, lower average costs can be achieved by operating multiple shifts. However, between 10,000 and 50,000 tons annually, results indicate that single-shift operations can produce far less. This latter implication conflicts with the blanket recommendation favoring multiple shifts. Such a blanket recommendation to the feed industry frequently is made.

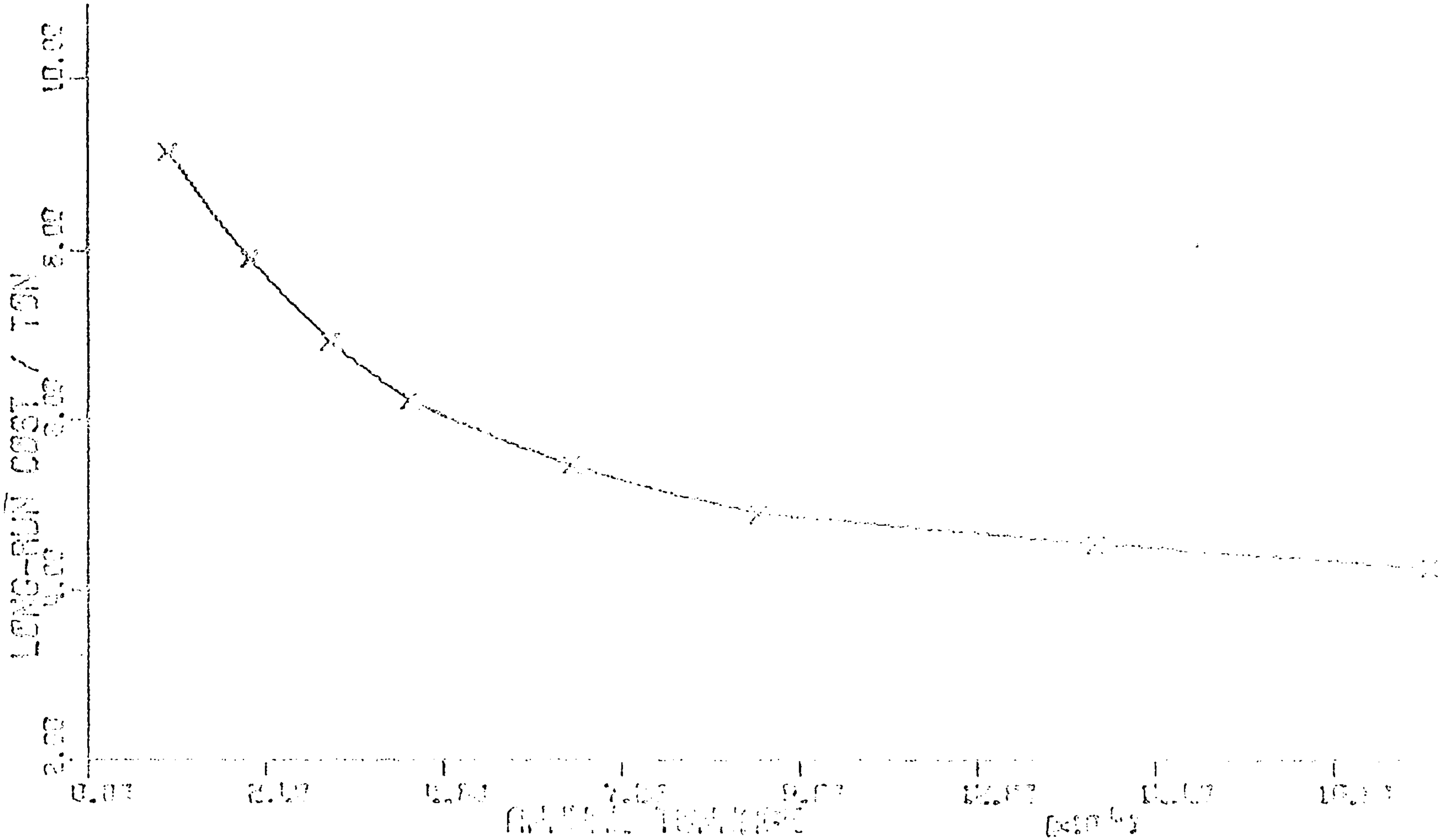

Figure 14. Long-run average cost function, double-shift synthesis

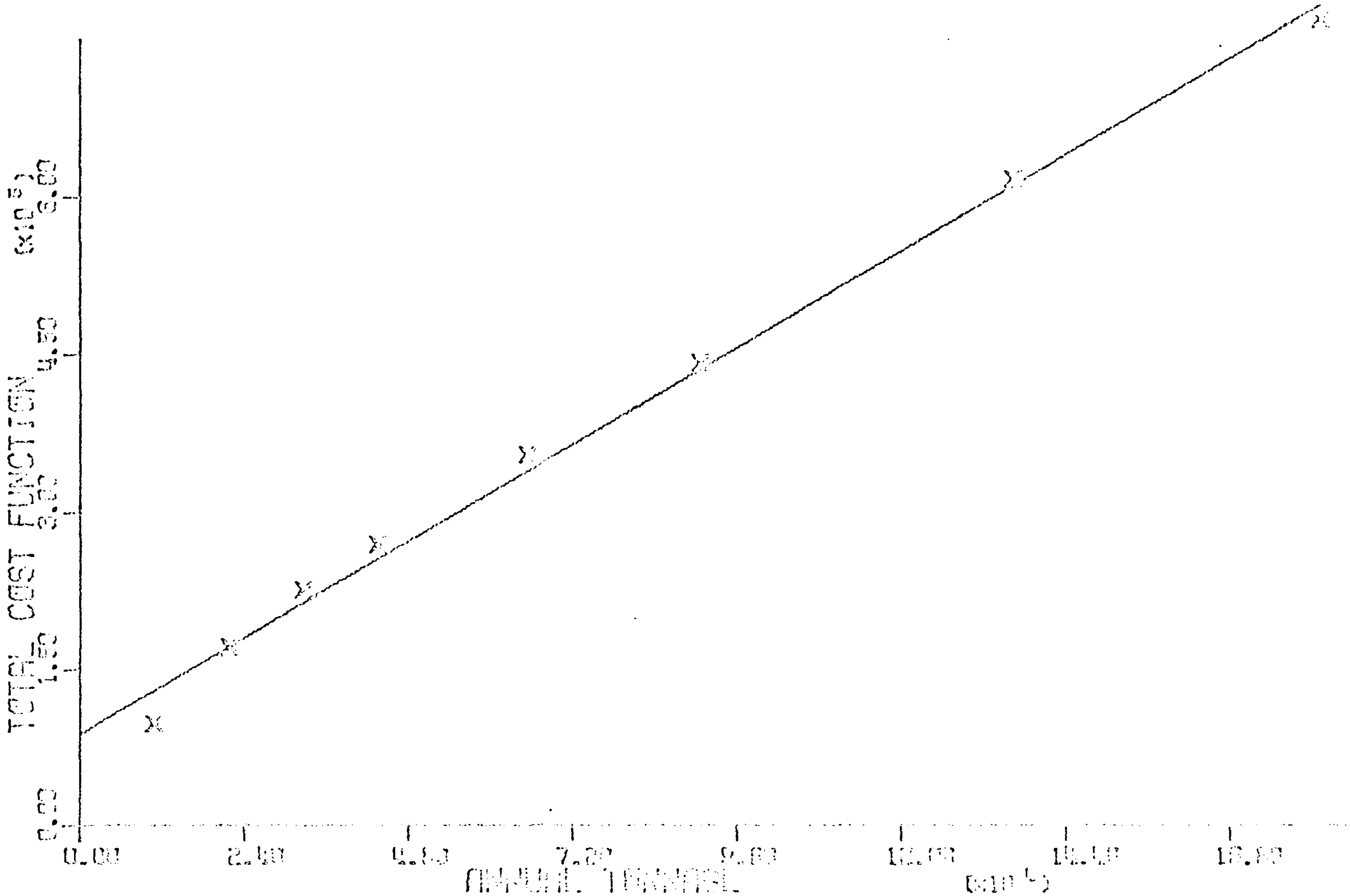

Figure 15. Long-run total cost function, double-shift synthesis

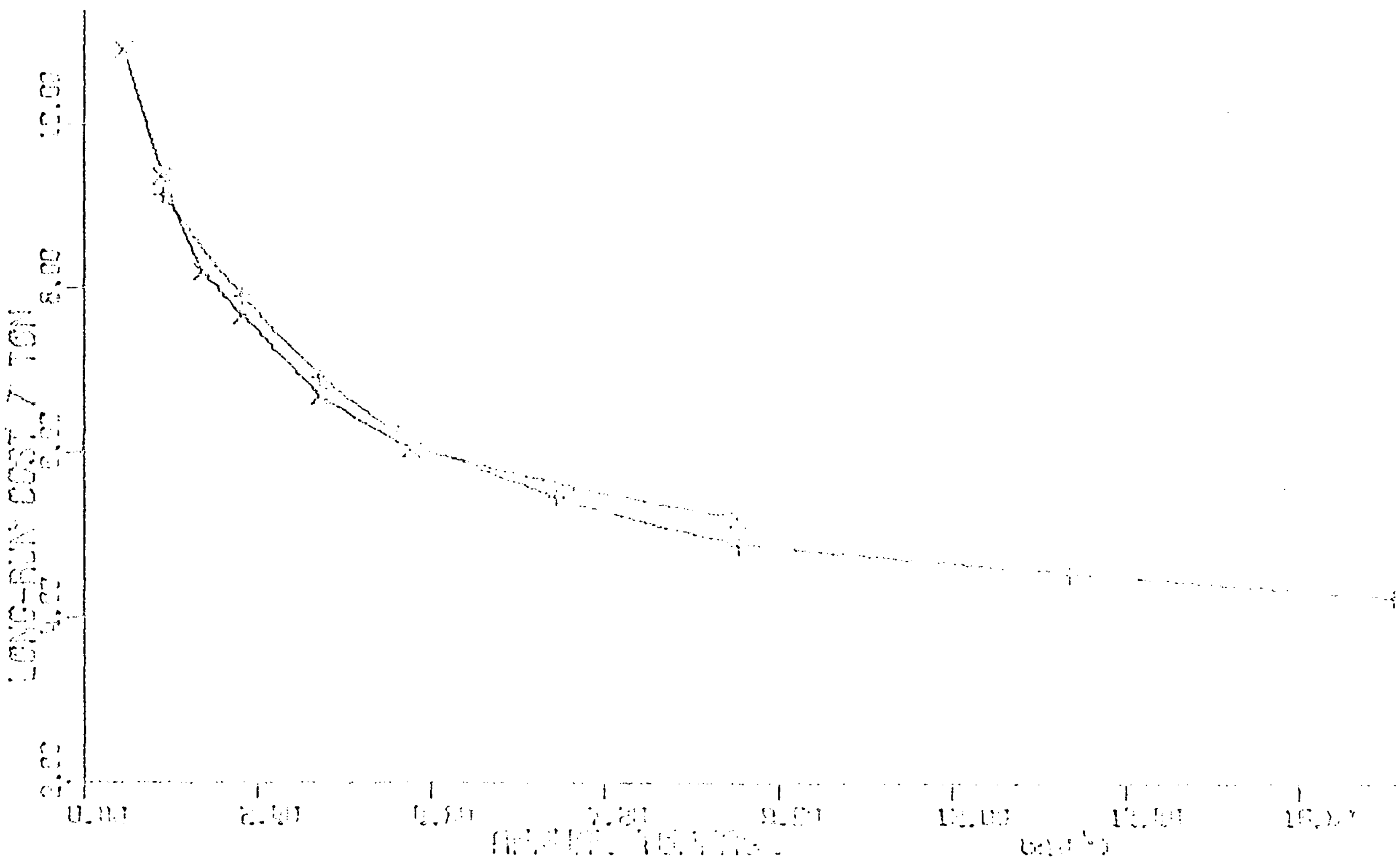

Figure 16. Long-run average cost functions, single-shift and double-shift syntheses

VII. MODEL APPLICATION

The data requirements of the present study's long-run spatial model were outlined in Chapter V. In Chapter VI, the development of these data requirements was detailed along with the results. The major data components for the model included estimates of feed tonnages to be supplied to each county, a road mileage transportation matrix for Iowa, analysis of transportation and selling costs to distribute the estimated feed tonnages and analysis of feed manufacturing costs in Iowa. The manufacturing cost analysis included consideration of both single- and double-shift operations.

The purpose of this chapter is to apply the long-run spatial model empirically and present the results. Two basic approaches will be followed in this application. The first will be referred to as the combinations approach while the second will be denoted the iterative approach. These two approaches require the minimization of total distribution costs with respect to location patterns, and both require the computation of total manufacturing costs with respect to number of locations. These costs are then summed to obtain a combined total cost function to be minimized with respect to the number of locations.

Earlier, the computational procedure for solving the model's combinations approach was outlined with the use of an example problem. For each possible number of plant locations, the plant location pattern which minimizes total distribution costs is determined. The results obtained indicate not only the cost-minimizing location pattern but which potential plant locations would supply each county's feed demand. Hence, the feed tonnage to be manufactured at each location also is ascertained. The feed manufacturing cost at each location can then be computed; when the manufacturing costs are summed across the number of locations and added to the minimized distribution costs, total combined costs have been calculated. Conceptually, once the total combined cost figure has been obtained for each possible number of plant locations, the minimum figure can be selected. The optimum has been reached in a context of cost minimization. The optimum solution gives the number of plant locations and the attendant distribution-cost-minimizing location pattern. In addition, the tonnage to be supplied from each plant location becomes available as does information indicating which plant locations in the solution should serve each county.

To illustrate, if only one plant is allowed in the model, Marshalltown is the best place to locate. If two are allowed, the best plant location pattern consists of Cedar Rapids and Storm Lake. Iowa City, Iowa Falls and Storm Lake make up the three-plant location pattern which minimizes costs. Each county would be served by one of the three locations. The tonnage to be supplied from each location becomes known so manufacturing costs can be calculated. Total combined cost is obtained by totaling the manufacturing cost and the minimized distribution cost for three plants.

The iterative approach was used in an effort to simulate business decisions feed manufacturing firms might be expected to make. Cost minimization was adopted as a guideline for the firm. In the model it was assumed that each firm was motivated toward cost minimization and that it possessed full information. It was assumed further that if the entry of an additional plant caused total aggregate industry cost (to supply the feed demand in each county) to rise, that plant would not enter. Plants would be located one by one; the entering plant would make its location decision on a basis of cost minimization but conditional upon the location of each of the previously located manufacturing entities. In each iteration, the previously located plants are retained and the plant location which would reduce total distribution costs the most would be permitted to enter. The minimized distribution costs in the iterative model approach would be expected to be greater than or equal to the minimized distribution costs in the combinations model approach.

As in the combinations approach, if one firm were to serve Iowa's feed demand, it would be expected to locate in Marshalltown. The difference between the combinations and iterative approaches can be illustrated with the choice of the second plant location. In the iterative approach, the plant location is selected which combines with Marshalltown to minimize distribution costs. This is Storm Lake. The feed tonnage to be produced at each of the two sites is determined and attendant manufacturing costs computed. As before, total manufacturing costs plus minimized total distribution costs equal total combined costs. The latter cost function minimum is sought. Conditional upon the existence of plants at Marshalltown and Storm Lake, the third plant should be located at Iowa City.

In general, the location of the k-th plant is conditional upon the location of the (k-1) plants.

It was pointed out earlier that Keokuk was at a disadvantage relative to Fort Madison. This was so for all 99 counties. The omission of Keokuk left 50 potential plant locations. The combinations approach to the long-run spatial model is extremely expensive to compute when there is a large number of potential plant locations. For example, 50 C 25 exceeds three trillion combinations. It was felt that several criteria made it reasonable to pare the number of potential plant locations to 40. Ten more population centers were eliminated (arbitrarily) from consideration: Boone, Independence, Knoxville, Maquoketa, Mount Pleasant, Pella, Perry, Red Oak, Shenandoah and Washington.

Initially, the sole criterion for inclusion as a potential plant location was that the 5,000 population minimum be met. However, not all such population centers would be equally desirable -- for reasons not explicitly considered in the model. Some centers are at a disadvantage because their road facilities are not as good as some competing centers. Certain centers were surrounded closely by bigger centers. Larger centers are likely to offer more external economies in terms of financial and insurance facilities, sales promotion services and expansion possibilities either by diversification or integration [Bain, 1965, pp. 177-182]. As a consequence, the ensuing empirical application will content with a 40-plant subset of the original 50 potential plant locations. The geographic dispersion of the 40-plant subset is illustrated in Figure 17.

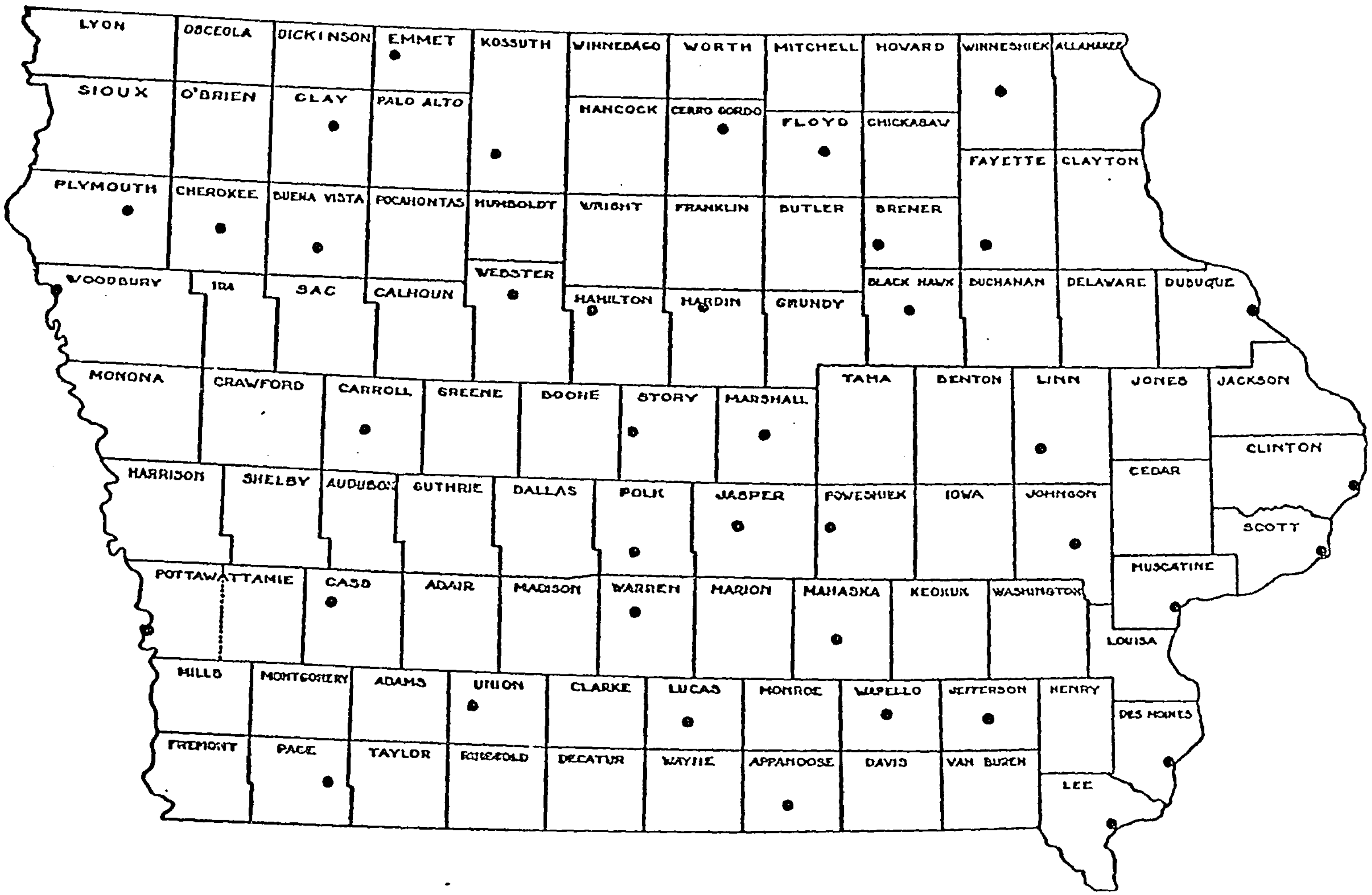

Figure 17. Geographic dispersion of 40-location population center subset

A. Distribution Costs with Respect to Numbers

1. Combinations approach

The optimization procedure includes minimizing distribution costs with respect to location patterns for each possible number of potential plant locations. With 40 potential plant locations, minimizing distribution costs with respect to location patterns would entail computing

$$40C_1,\ 40C_2,\ \ldots,\ 40C_{39},\ 40C_{40}.$$

For each, manufacturing costs are added to minimized distribution costs to obtain total combined costs.

If important model assumptions hold concerning the minimized distribution cost function and the manufacturing cost function, the total combined cost function will be convex. These assumptions are: the first differences of the minimized distribution cost function with respect to plant numbers are negative; the second differences of the minimized distribution cost function with respect to plant numbers are positive; and the feed manufacturing cost functions are linear. The convex total combined cost function can be minimized without computing all conceivable combinations. Therefore, the computational cost burden is relieved somewhat.

Nevertheless, computational cost considerations made it impossible to follow the model's optimization procedure precisely. For example, some experimentation with the model revealed that only two combinations per second could be computed on the "high" end --

$40C_{37}$ would take about 85 minutes to compute and $40C_{36}$ would take about 765 minutes. On the "low" end, about 31 combinations per second could be computed; yet $40C_4$ would take about 50 minutes to compute. Consequently, a suboptimization procedure was pursued.

The suboptimization procedure involved working from the "high" end; that is, computing $40C_{40}$, $40C_{39}$, $40C_{38}$, etc. If a plant was eliminated by the model on two successive runs, it was permanently removed. To wit: Clinton was eliminated by computing $40C_{39}$ and it was one of two sites eliminated in the $40C_{38}$ computation; thus, Clinton was permanently removed as a location contender and the next computing step was based upon 39 potential plant locations. Continuing the example explanation, since the site removed by $39C_{38}$ (same result as $40C_{38}$) was one of two removed by $39C_{37}$, that potential plant location was removed from consideration. In each step manufacturing costs and total combined costs were computed. The procedure was continued as long as the total combined cost function decreased with each decrease in number of plant locations. Eventually a total combined cost function minimum was reached. Then combined costs rose with decreases in plant location numbers.

Once total combined costs began to rise, it was not necessary to program further calculations. Actually, three further steps were programmed to check for total combined cost function convexity in the neighborhood of the suboptimization solution. The convexity was confirmed. Three computations on the "low" end were performed

($40C_1$, $40C_2$ and $40C_3$) because it was relatively inexpensive to obtain this information.

The configuration of the combinations approach minimized distribution cost function is presented in Figure 18. The numerical results are presented in Table 24. This table also contains other results pertinent to the combinations approach.

As the number of locations increases, total minimized distribution costs decrease sharply when only a few locations are considered. But as the number of locations considered becomes large, the slope of the total minimized distribution cost function becomes small.

The empirical results confirm two important assumptions of the model. The signs of all first differences were negative,

$$\frac{\Delta TDC^{min}}{\Delta J} < 0.$$

All second differences were found to be positive,

$$\frac{\Delta^2 TDC^{min}}{\Delta J^2} \geq 0.$$

2. Iterative approach

With one important exception, the basic solution procedure is the same for the iterative approach as for the combinations approach. The exception is that the minimized distribution costs calculations are subject to an additional constraint -- locations previously selected by the model are retained. Then feed manufacturing costs are added to obtain the total combined cost function.

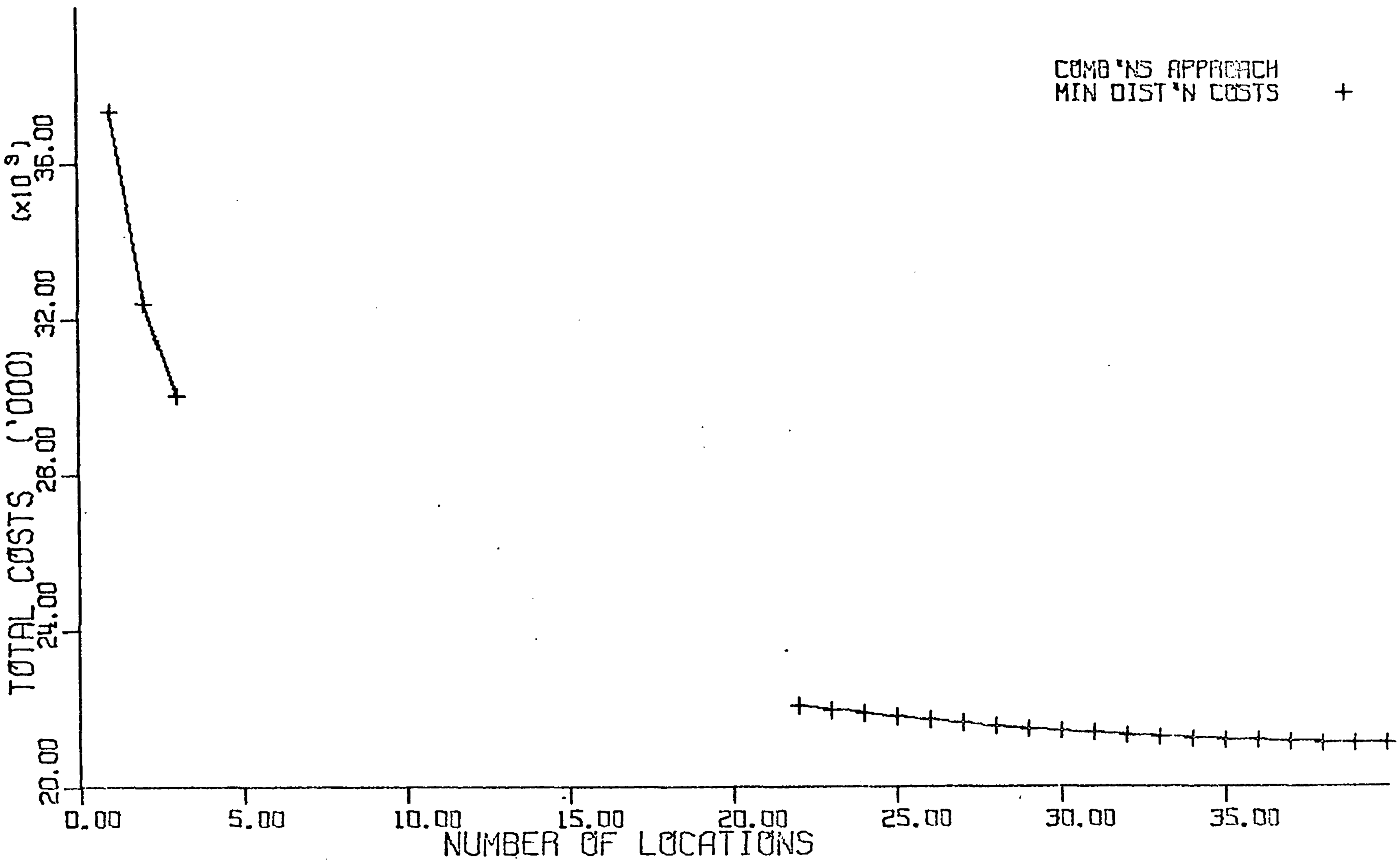

Figure 18. Minimized total distribution cost function, combinations approach

TABLE 24. COMBINATIONS APPROACH. MINIMIZED TOTAL DISTRIBUTION COSTS, SINGLE-SHIFT AND MULTI-SHIFT MANUFACTURING COSTS, AND RESPECTIVE TOTAL COMBINED COSTS, IN THOUSANDS OF DOLLARS

NUMBER OF PLANTS	MINIMIZED DIST N COSTS	SINGLE -SHIFT MFG COSTS	MULTI -SHIFT MFG COSTS	COMBINED COSTS (SINGLE)	COMBINED COSTS (MULTI)
1	37323	16704	13596	54028	50920
2	32415	16757	13686	49172	46101
3	30050	16811	13776	46861	43827
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
22	22074	17822	15488	39895	37562
23	21975	17874	15578	39850	37552
24	21878	17928	15668	39806	37546
25	21788	17981	15758	39769	37546
26	21703	18034	15848	39737	37551
27	21621	18088	15938	39709	37559
28	21545	18141	16028	39686	37573
29	21483	18194	16118	39677	37601
30	21432	18247	16208	39679	37640
31	21383	18300	16298	39683	37681
32	21337	18354	16388	39690	37725
33	21296	18407	16478	39702	37774
34	21255	18460	16568	39715	37824
35	21216	18513	16658	39729	37874
36	21184	18566	16749	39750	37932
37	21157	18620	16839	39776	37995
38	21135	18673	16929	39808	38063
39	21114	18726	17019	39840	38132
40	21102	18779	17109	39881	38210

Starting with zero, plants were added one by one. Cost minimization with respect to location patterns was the criterion for selection of the entering location. One plant location was added in each iteration. The model selected the plant location which combined with previously selected locations to distribute the estimated Iowa feed demand at the lowest cost.

For a given number of plant locations, the number of location pattern alternatives in the iterative approach to the long-run spatial model is a fraction of the alternatives in the combinations approach. Model computing costs are related directly to the number of location pattern alternatives. In the combinations approach, each conceivable combination represents a possible location pattern -- an exceedingly high number in most cases. The number of possible location patterns in the iterative approach equals only the number of potential plant locations not yet selected. Therefore, the iterative approach was relatively inexpensive to compute.

The iterative approach to solving the long-run spatial model is a suboptimization procedure. Not all possibilities are computed in the sense of the basic model. The iterative approach was applied empirically to the 40-plant set of potential plant locations set forth earlier. Given validity of assumptions resulting in total combined cost function convexity, calculations for the full range of plant location numbers would not be necessary. However, the full range of calculations were performed since it was not prohibitively expensive to do so. Figure 19 graphs the relation of minimized total distribution

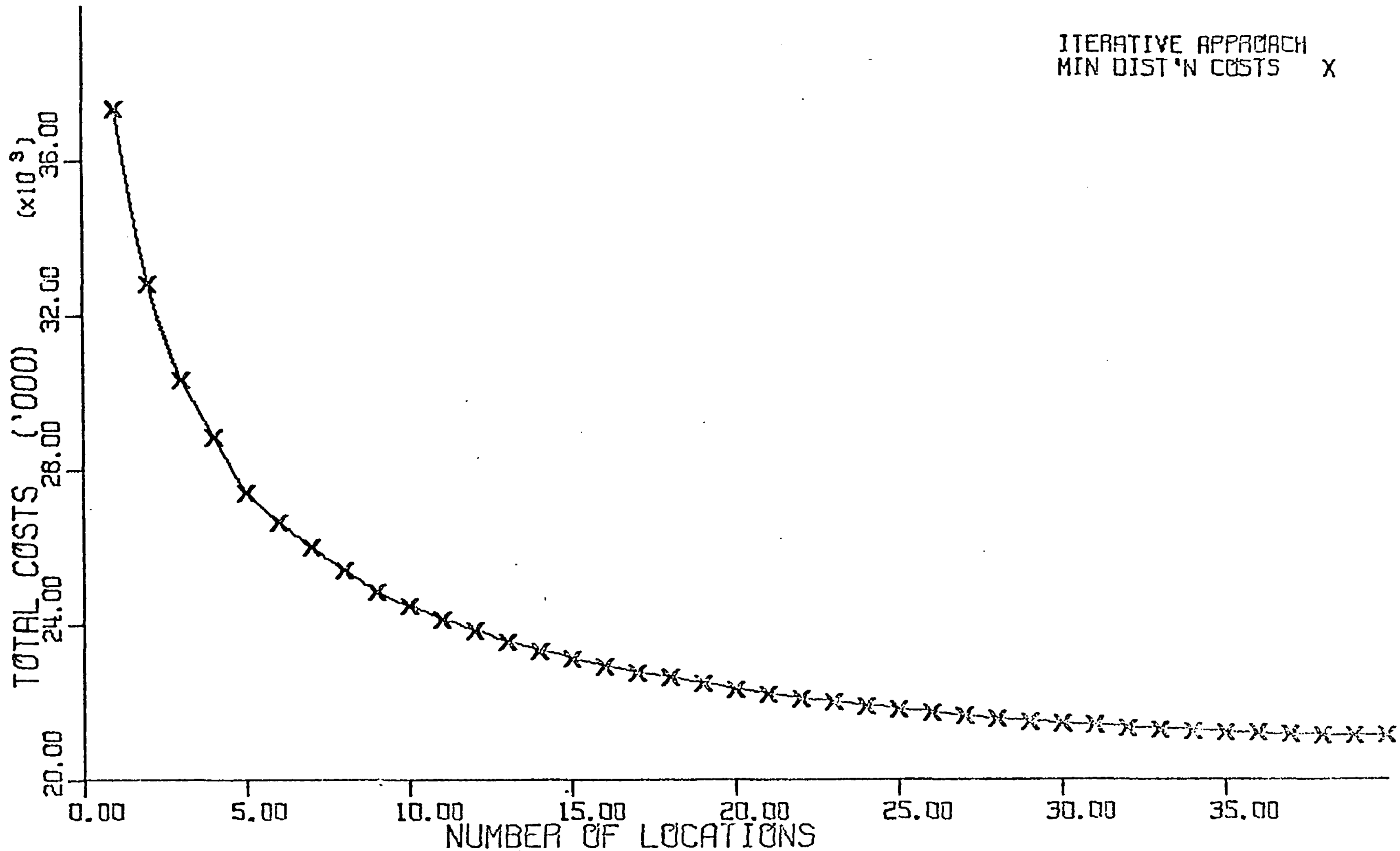

Figure 19. Minimized total distribution cost function, iterative approach

costs to number of plant locations. The numerical results are presented in Table 25 along with other costs pertinent to the iterative approach.

When there are few locations considered, minimized total distribution costs decrease sharply as the number of locations is increased. The rate of decrease becomes smaller as the number of potential plant locations considered becomes larger. As in the combinations approach, iterative approach empirical results confirm the model's assumptions regarding first and second difference signs. All first differences were negative and all second differences were positive.

The minimized total distribution cost functions for the combinations and iterative approaches can be compared by referring to Figures 18 and 19. As would be expected, the iterative approach function is greater than or equal to the combinations approach function. Obviously, they must be equal when either 40 plants or only one plant are allowed in the model. Each approach would select Marshalltown if only one plant was to serve the entire state; $40C_{40}$ yields only one combination.

Empirical results indicate that from 28 to 40 plants, the respective functions are equal. As a result, the respective manufacturing and combined cost functions will be equal. In general, the difference is small between the two minimized total distribution cost functions. The small difference indicates that the iterative approach may be very useful for approximating the least-cost location pattern -- especially if the optimal solution should include a large number of plant locations. The iterative approach has the practical advantage of being relatively inexpensive to apply empirically.

TABLE 25. ITERATIVE APPROACH. MINIMIZED TOTAL DISTRIBUTION COSTS, SINGLE-SHIFT AND MULTI-SHIFT MANUFACTURING COSTS, AND RESPECTIVE TOTAL COMBINED COSTS, IN THOUSANDS OF DOLLARS

NUMBER OF PLANTS	MINIMIZED DIST N COSTS	SINGLE -SHIFT MFG COSTS	MULTI -SHIFT MFG COSTS	COMBINED COSTS (SINGLE)	COMBINED COSTS (MULTI)
1	37323	16704	13596	54028	50920
2	32796	16757	13686	49554	46483
3	30317	16811	13776	47128	44094
4	28836	16864	13866	45700	42703
5	27384	16917	13957	44301	41341
6	26646	16970	14047	43616	40693
7	25988	17024	14137	43011	40124
8	25393	17077	14227	42469	39619
9	24828	17130	14317	41958	39145
10	24469	17183	14407	41652	38876
11	24139	17236	14497	41376	38636
12	23848	17290	14587	41138	38435
13	23570	17343	14677	40912	38247
14	23336	17396	14767	40732	38104
15	23127	17449	14857	40576	37984
16	22923	17502	14947	40425	37870
17	22773	17556	15037	40329	37811
18	22624	17609	15127	40233	37752
19	22478	17662	15217	40140	37695
20	22335	17715	15308	40050	37642
21	22198	17768	15398	39966	37595
22	22091	17822	15488	39912	37579
23	21992	17875	15578	39867	37570
24	21896	17928	15668	39824	37564
25	21806	17981	15758	39787	37563
26	21717	18034	15848	39752	37565
27	21630	18088	15938	39718	37568
28	21545	18141	16028	39686	37573
29	21483	18194	16118	39677	37601
30	21432	18247	16208	39679	37640
31	21383	18300	16298	39683	37681
32	21337	18354	16388	39690	37725
33	21296	18407	16478	39702	37774
34	21255	18460	16568	39715	37824
35	21216	18513	16658	39729	37874
36	21184	18566	16749	39750	37932
37	21157	18620	16839	39776	37995
38	21135	18673	16929	39808	38063
39	21114	18726	17019	39840	38132
40	21102	18779	17109	39881	38210

B. Feed Manufacturing Costs with Respect to Numbers

In Chapter VI, economic-engineering methods were used to synthesize volume-cost relationships in feed manufacturing operations. Long-run average cost was developed for each of eight model plant sizes. The product of tonnage volumes and long-run average costs yielded total costs. The total cost points indicated linear relationships with annual tonnage volumes. Linear regressions were computed. Cost analysis was undertaken for both single-shift operations and multi-shift operations (a day shift and a night shift). The regression results indicated that both total cost functions were linear. But the computed equations did differ.

The estimated total cost function equation for single-shift feed manufacturing operations was

$$TC = 53202.5 + 4.74083\ V.$$

The R^2 was 0.994. Both the intercept and slope parameters proved to be significantly different from zero when tested statistically.

For multi-shift feed manufacturing operations the estimated total cost function equation was

$$TC = 90064.25 + 3.84544\ V.$$

The R^2 was 0.995 while the intercept and slope parameters were significantly different from zero.

The range of plant tonnages covered by the single-shift equation estimation is from 5,434 to 90,577 tons annually. Each output volume is doubled for the multi-shift equation estimation. The range is from 10,868 to 181,154 tons annually.

1. Application in the model

Total manufacturing costs were computed for each number of plant locations considered. This was the case for both the combinations and iterative approaches to computing the long-run spatial model's solution. In each approach the single-shift and multi-shift manufacturing costs were calculated. The results were obtained using the estimated linear equations.

The nature of the feed manufacturing cost calculations was established by minimizing the distribution costs with respect to location pattern. For any given number of plant locations the minimized total distribution cost function established which locations should serve each county's feed demand. Hence, the tonnage to be manufactured at each location was calculated. Then the respective linear equations were used to estimate total manufacturing costs.

When few locations were considered, application of the estimated manufacturing cost functions involved extrapolating beyond the volume ranges used in the estimations. Extrapolating the linear total cost function implies that economies of scale are never exhausted; but the rate of decrease in the long-run average cost function decreases to a very small magnitude. The average cost functions become roughly constant at volumes not greatly beyond the maximum volumes used in the regression estimations. Comparing the rate of average cost decrease with the extrapolated rate of plant volume size increase, a one-half cent decrease per 1,000 ton size increase is reached at 110,000 tons annually for the single-shift cost function. The one-quarter cent rate of decrease is reached at 150,000 tons. For the multi-shift cost function a one-half cent decrease per 1,000 ton size increase is reached at 140,000 tons annually. At 200,000 tons the one-quarter cent rate of decrease is reached.

Economic theory suggests that diseconomies of scale exist. Empirical data available to the present study do not suggest diseconomies of scale. Perhaps if observations on larger plants had been available, indications of diseconomies might have been detected.

The most extreme case possible in the model is for one plant location to serve the entire estimated Iowa feed demand of 3.5 million tons. It seems extreme to visualize a feed manufacturing establishment this large. It is more realistic to suppose that several separate plants would be established. Among single-shift operations there might be 32 plants (each of 110,000 tons annual capacity) if the one-half cent per 1,000 tons rate of average cost decrease is accepted as representing constancy. If the one-quarter cent rate is regarded as average cost constancy, there might be 23 plants with a capacity of 150,000 tons annually. The respective results for multi-shift operations might suggest 25 plants of 140,000 tons annual capacity or eighteen 200,000 ton plants. Of course, some combination of single- and multi-shift operations would be possible. One company (or cooperative) might own them all. However, 32 firms could own one 110,000 ton establishment each. Again, all of these would be located at Marshalltown.

As larger numbers of potential plants were considered, the application of the estimated cost equations became more realistic. In general, the tonnages to be manufactured at each selected location became less as more locations entered. Therefore, the tonnages to be supplied at each site approached the volume ranges used in estimating the total manufacturing cost functions. This topic will be alluded to later when the model solutions are discussed.

2. Results

Along with other cost results pertinent to the combinations approach, manufacturing cost results are presented in Table 24. One vector of results refers to single-shift operations while another refers to the multi-shift alternative. Cost results referring to the iterative approach are set forth in Table 25. For each approach, the two manufacturing cost vectors are identical. That is, comparing the combinations and the iterative approaches, for k potential plant locations the single- and multi-shift manufacturing costs are the same.

One important assertion about the long-run spatial model was that total industry manufacturing cost would increase, with each additional potential plant location, by the intercept of the estimated linear equation for plant costs. Empirical results confirm this assertion for both single- and multi-shift manufacturing operations. The relationship is linear between total industry manufacturing costs and plant numbers. Furthermore, the slope of this function equals the intercept of the estimated equation for plant manufacturing costs.

The linear nature of these important relationships is depicted in Figure 20. Throughout the range of the abscissa, the multi-shift function lies below the single-shift function. Their slopes differ since their respective estimated intercept values differ (in the total plant cost functions).

C. Total Combined Costs with Respect to Numbers

The total combined cost function was obtained by vertical summation of the minimized total distribution function and the total manufacturing cost function. Each of these three functions is with respect to number of potential plant locations. The solution for the long-run spatial model is the minimum point on the total combined cost function. The distribution cost function is negatively sloped while the manufacturing cost function has a positive slope. As long as the absolute value of the distribution cost function slope exceeded the manufacturing cost function's slope, the combined cost function decreased with respect to plant location numbers. Of course, the converse is true. The combined cost function was at a minimum when the absolute values of the two slopes were equal; that is,

$$\left| \beta_D \right| = \left| \beta_M \right|$$

where the betas are the respective slope magnitudes.

1. Combinations approach solutions

Figure 21 is a graph of the numerical results in Table 24. There is a solution for single-shift operations and another for multi-shift

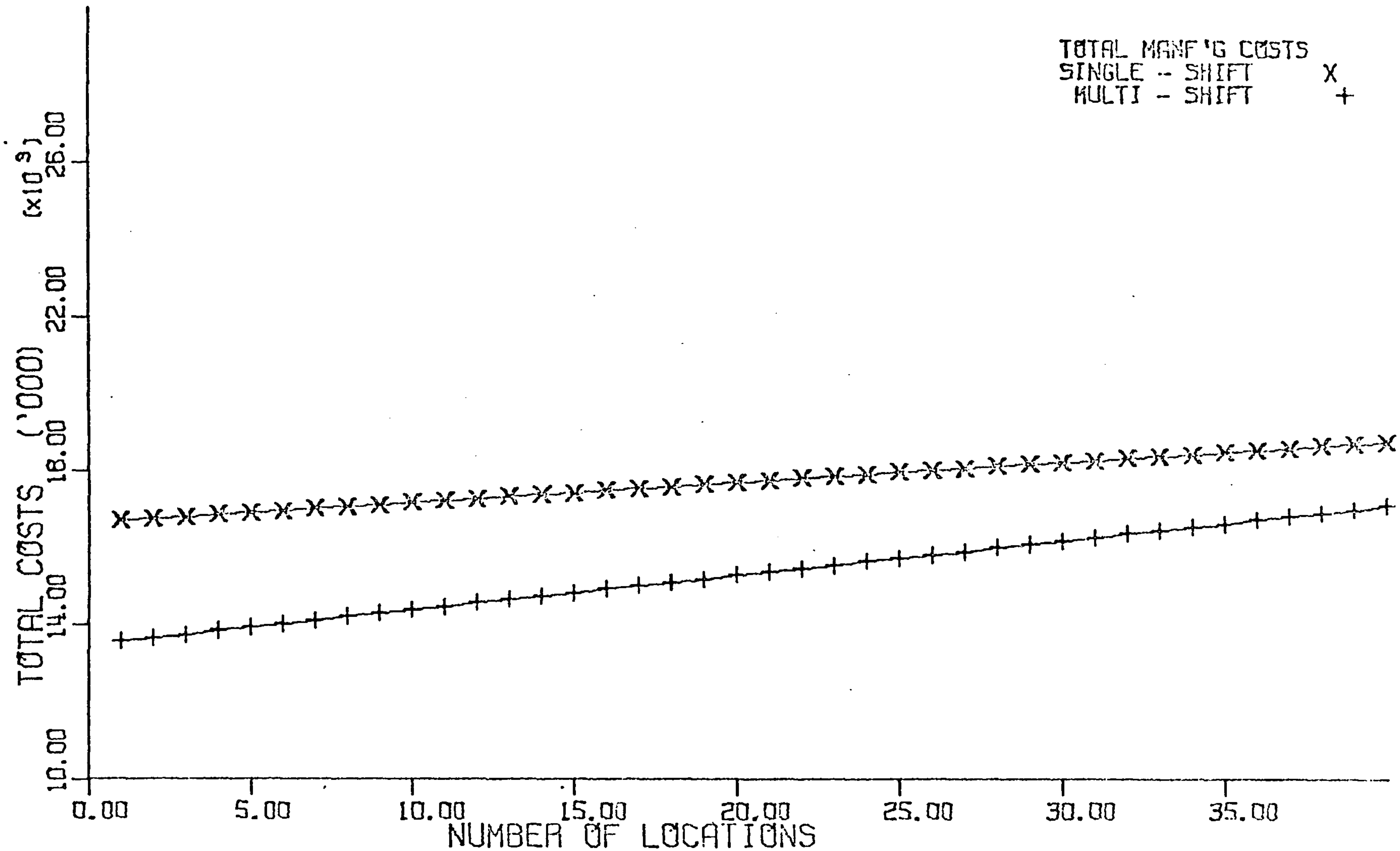

Figure 20. Total manufacturing cost functions for single-shift and multi-shift operations

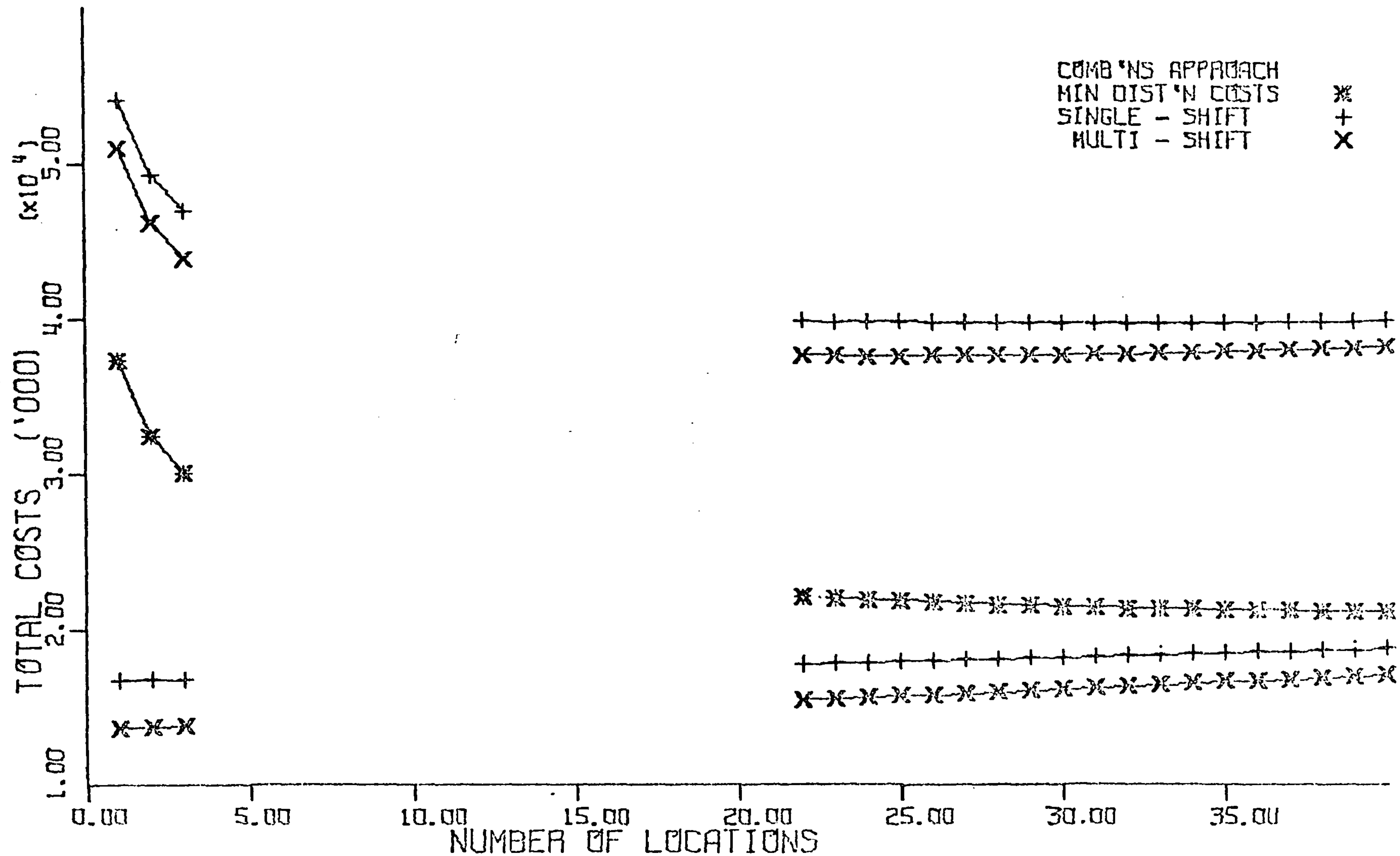

Figure 21. Combinations approach total combined cost functions, single-shift and multi-shift operations

operations. The solutions can be read from the results of Table 24 or from careful examination of Figure 21.

The single-shift combinations approach solution is 29 plant locations. For 29 plants the minimized total distribution costs were $21,483,200 while the accompanying total manufacturing costs were $18,193,952. The total combined costs were $39,677,152. The estimated feed tonnage demand for Iowa was 3,512,269 tons. The per ton combined cost was $11.30 for the single-shift solution. The breakdown was $6.12 per ton for minimized distribution costs and $5.18 per ton for manufacturing costs.

An important feature of the model is that it was programmed to show which locations should serve the feed demand of which counties. In Table 26 each site of the 29-location solution is specified along with the counties to be supplied from each location. The tonnage of each county is noted as is the tonnage to be manufactured at each location site.

The solution is illustrated further in Figure 22. A number appears in each of the 99 Iowa counties. For each county the number refers to one of the 29 "location number" entries from Table 26. The number tells which location should supply a particular county's estimated feed demand. For example, a "10" in Harrison County indicates that a location in Council Bluffs should supply feed to that county.

The total combined cost function for multi-shift operations lies below that for single-shift operations. This can be seen in Figure 21. Since the slope of the multi-shift manufacturing function differs

Table 26. Single-shift combinations approach: 29-plant solution location, counties served by each, estimated feed tonnage per county and tonnages to be manufactured at each plant location

Location number	Location name	Counties served	County tonnages	Location tonnages
1	Algona	Humboldt	24,178	
		Kossuth	59,280	
		Palo Alto	28,567	
				112,025
2	Ames	Boone	34,098	
		Dallas	30,562	
		Polk	20,429	
		Story	37,280	
				122,369
3	Atlantic	Audubon	36,501	
		Cass	33,826	
		Shelby	43,279	
				113,606
4	Burlington	Des Moines	20,634	
		Lee	22,313	
				42,917
5	Carroll	Calhoun	28,633	
		Carroll	51,763	
		Crawford	51,010	
		Greene	27,519	
		Guthrie	27,335	
				186,260
6	Cedar Rapids	Benton	56,975	
		Jones	48,824	
		Linn	42,802	
				148,601
7	Centerville	Appanoose	11,335	
		Davis	13,203	
		Decatur	12,037	
		Monroe	10,957	
		Wayne	18,903	
				66,435
8	Charles City	Chickasaw	34,459	
		Floyd	31,977	
		Mitchell	37,253	
				103,689

Table 26. (Continued)

Location number	Location name	Counties served	County tonnages	Location tonnages
9	Clarinda	Fremont	12,741	
		Montgomery	24,988	
		Page	29,358	
		Taylor	20,365	
				87,452
10	Council Bluffs	Harrison	23,057	
		Mills	18,978	
		Monona	22,313	
		Pottawattamie	58,177	
				122,525
11	Creston	Adair	31,053	
		Adams	19,881	
		Ringgold	16,195	
		Union	15,658	
				82,787
12	Davenport	Clinton	60,715	
		Scott	42,421	
				103,136
13	Decorah	Allamakee	31,265	
		Howard	28,080	
		Winneshiek	50,068	
				109,413
14	Dubuque	Delaware	58,866	
		Dubuque	49,632	
		Jackson	37,234	
				145,732
15	Fairfield	Henry	34,746	
		Jefferson	19,716	
		Van Buren	16,156	
		Wapello	14,337	
				84,955
16	Indianola	Clarke	15,292	
		Lucas	14,254	
		Madison	23,046	
		Warren	22,969	
				75,561
17	Iowa City	Cedar	61,225	
		Iowa	46,041	
		Johnson	54,606	
		Washington	62,848	
				224,720

Table 26. (Continued)

Location number	Location name	Counties served	County tonnages	Location tonnages
18	Iowa Falls	Franklin	46,304	
		Hardin	44,462	
				90,766
19	Le Mars	Lyon	41,247	
		Plymouth	75,195	
		Sioux	76,466	
		Woodbury	53,832	
				246,740
20	Marshalltown	Grundy	40,851	
		Marshall	35,274	
		Tama	51,304	
				127,429
21	Mason City	Cerro Gordo	41,711	
		Hancock	42,927	
		Winnebago	29,011	
		Worth	28,040	
				141,689
22	Muscatine	Louisa	22,319	
		Muscatine	30,553	
				52,872
23	Newton	Jasper	48,136	
		Poweshiek	36,150	
				84,286
24	Oelwein	Buchanan	39,900	
		Clayton	49,196	
		Fayette	46,395	
				135,491
25	Oskaloosa	Keokuk	43,474	
		Mahaska	44,706	
		Marion	32,307	
				120,487
26	Spencer	Clay	30,745	
		Dickinson	18,496	
		Emmet	17,469	
		O'Brien	43,088	
		Osceola	24,316	
				134,114
27	Storm Lake	Buena Vista	44,764	
		Cherokee	44,657	
		Ida	37,888	
		Pocahontas	35,119	
		Sac	44,777	
				207,205

Table 26. (Continued)

Location number	Location name	Counties served	County tonnages	Location tonnages
28	Waverly	Black Hawk	41,759	
		Bremer	33,787	
		Butler	42,737	
				118,283
29	Webster City	Hamilton	56,355	
		Webster	26,707	
		Wright	37,633	
				120,695

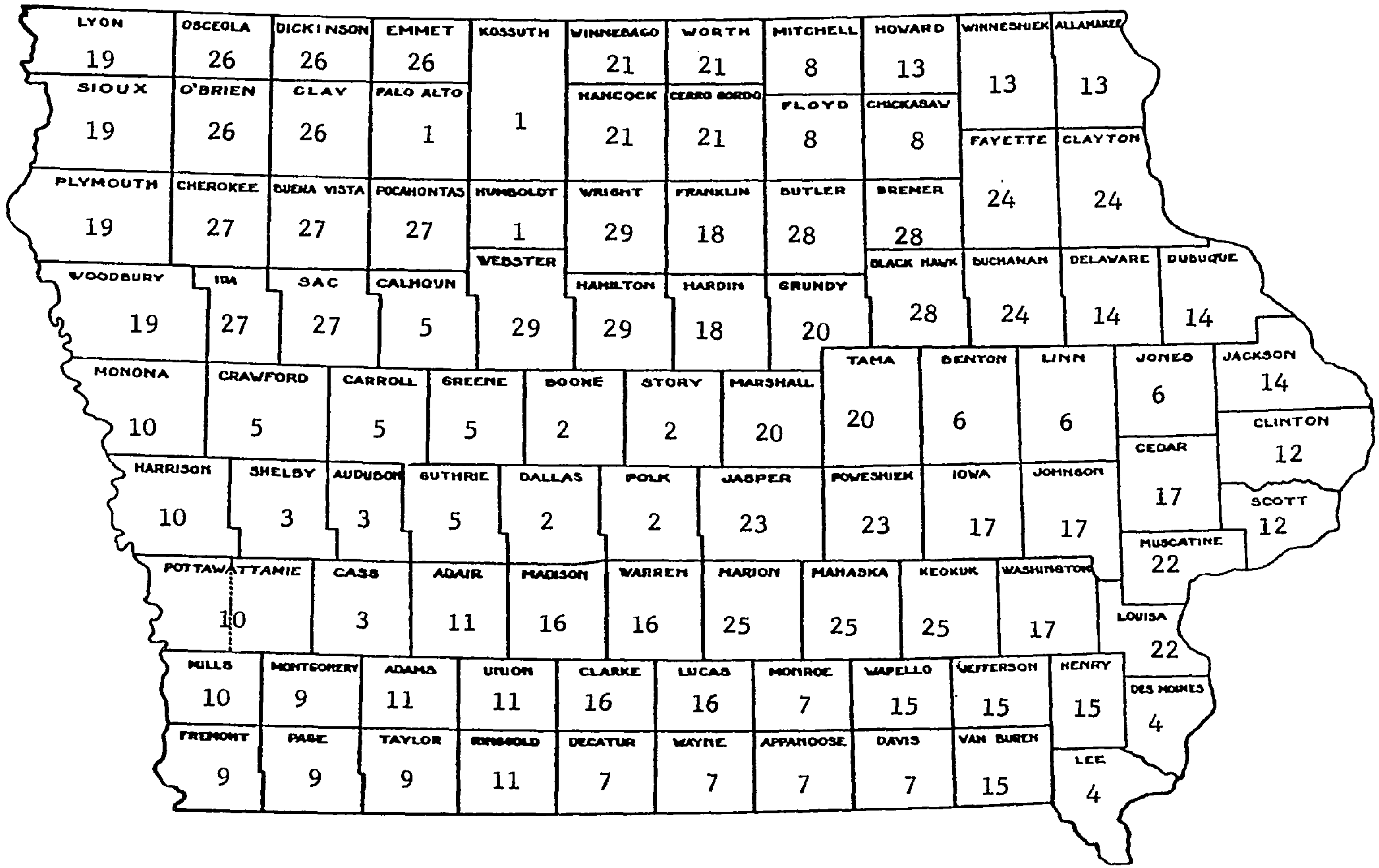

Figure 22. Combinations approach single-shift solution -- plant locations (by number) supplying feed demand of each county

from that for single-shift, the solution differs. The total combined cost minimum was reached at 25 plants.

Minimized total distribution costs for the 25-plant solution were $21,788,016. Multi-shift total manufacturing costs were $15,757,821. The total combined costs to manufacture and distribute 3,512,269 tons of feed would be $37,545,824.[1] The respective average costs per ton were $6.20, $4.49 and $10.69.

Comparing the single- and multi-shift solutions, multi-shift distribution costs are higher because the solution contains fewer locations. On the other hand, manufacturing costs are considerably lower; yet average combined costs for the multi-shift combinations approach are lower by 61 cents per ton. These results would suggest that over-all industry costs can be reduced by operating multiple shifts.

The plant locations-to-counties set of relationships is shown in Table 27. The results show, for each county, which of the 25 plant locations should serve the estimated feed tonnage demand. The county and location feed tonnages also are noted. The combinations approach multi-shift solution is illustrated further in Figure 23. The explanation parallels that for Figure 22. However, there are four fewer plant locations. Council Bluffs, Charles City, Muscatine and Indianola were eliminated from the 29-plant set that comprised the single-shift solution.

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[1]The seventh and eighth digits do not total because of rounding error.

Table 27. Multi-shift combinations approach: 25-plant solution locations, counties served by each, estimated feed tonnage per county and tonnages to be manufactured at each plant location

Location number	Location name	Counties served	County tonnages	Location tonnages
1	Algona	Humboldt	24,178	
		Kossuth	59,280	
		Palo Alto	28,567	
				112,025
2	Ames	Boone	34,098	
		Dallas	30,562	
		Polk	20,429	
		Story	37,280	
		Warren	22,969	
				145,338
3	Atlantic	Audubon	36,501	
		Cass	33,826	
		Harrison	23,057	
		Pottawattamie	58,177	
		Shelby	43,279	
				194,840
4	Burlington	Des Moines	20,634	
		Lee	22,313	
		Louisa	22,319	
				65,266
5	Carroll	Calhoun	28,633	
		Carroll	51,763	
		Crawford	51,010	
		Greene	27,519	
		Guthrie	27,335	
				186,260
6	Cedar Rapids	Benton	56,975	
		Jones	48,824	
		Linn	42,802	
				148,601
7	Centerville	Appanoose	11,335	
		Davis	13,203	
		Decatur	12,037	
		Lucas	14,254	
		Monroe	10,957	
		Wayne	18,903	
				80,689

Table 27. (Continued)

Location number	Location name	Counties served	County tonnages	Location tonnages
8	Clarinda	Fremont	12,741	
		Mills	18,978	
		Montgomery	24,988	
		Page	29,358	
		Taylor	20,365	
				106,430
9	Creston	Adair	31,053	
		Adams	19,881	
		Clarke	15,292	
		Madison	23,046	
		Ringgold	16,195	
		Union	15,658	
				121,125
10	Davenport	Clinton	60,715	
		Muscatine	30,553	
		Scott	42,421	
				133,689
11	Decorah	Allamakee	31,265	
		Howard	28,080	
		Winneshiek	50,068	
				109,413
12	Dubuque	Delaware	58,866	
		Dubuque	49,632	
		Jackson	37,234	
				145,732
13	Fairfield	Henry	34,746	
		Jefferson	19,716	
		Van Buren	16,156	
		Wapello	14,337	
				84,955
14	Iowa City	Cedar	61,225	
		Iowa	46,041	
		Johnson	54,606	
		Washington	62,848	
				224,720
15	Iowa Falls	Franklin	46,304	
		Hardin	44,462	
				90,766

Table 27. (Continued)

Location number	Location name	Counties served	County tonnages	Location tonnages
16	Le Mars	Lyon	41,247	
		Monona	22,313	
		Plymouth	75,195	
		Sioux	76,466	
		Woodbury	53,832	
				269,053
17	Marshalltown	Grundy	40,851	
		Marshall	35,274	
		Tama	51,304	
				127,429
18	Mason City	Cerro Gordo	41,711	
		Floyd	31,977	
		Hancock	42,927	
		Mitchell	37,253	
		Winnebago	29,011	
		Worth	28,040	
				210,919
19	Newton	Jasper	48,136	
		Poweshiek	36,150	
				84,286
20	Oelwein	Buchanan	39,900	
		Clayton	49,196	
		Fayette	46,395	
				135,491
21	Oskaloosa	Keokuk	43,474	
		Mahaska	44,706	
		Marion	32,307	
				120,487
22	Spencer	Clay	30,745	
		Dickinson	18,496	
		Emmet	17,469	
		O'Brien	43,088	
		Osceola	24,316	
				134,114
23	Storm Lake	Buena Vista	44,764	
		Cherokee	44,657	
		Ida	37,888	
		Pocahontas	35,119	
		Sac	44,777	
				207,205

Table 27. (Continued)

Location number	Location name	Counties served	County tonnages	Location tonnages
24	Waverly	Black Hawk	41,759	
		Bremer	33,787	
		Butler	42,737	
		Chickasaw	34,459	
				152,742
25	Webster City	Hamilton	56,355	
		Webster	26,707	
		Wright	37,633	
				120,695

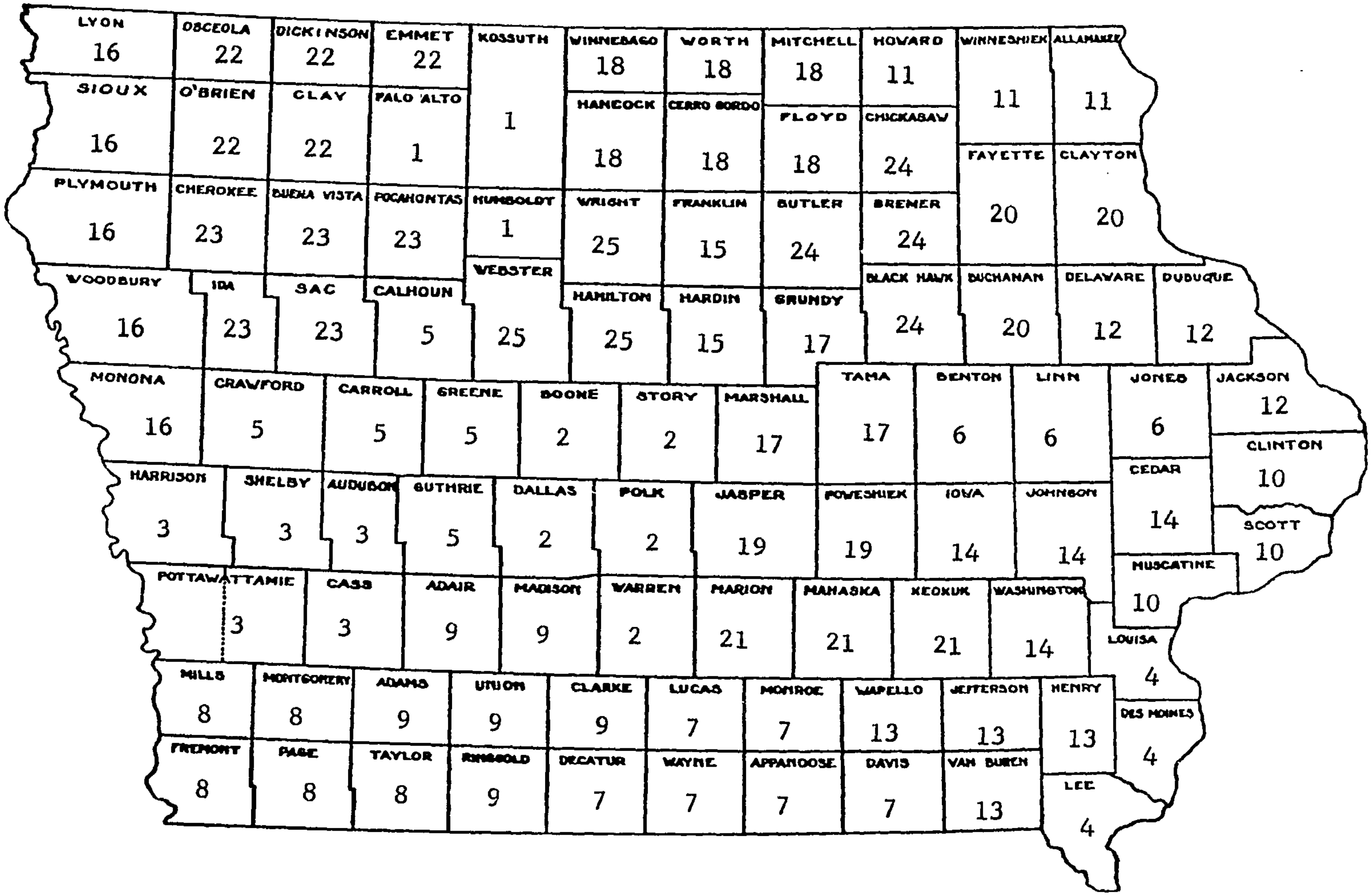

Figure 23. Combinations approach multi-shift solution -- plant locations (by number) supplying feed demand of each county

2. Iterative approach solutions

The iterative approach solution results were presented in Table 25 and are depicted in Figure 24. As in the combinations approach, there is a single-shift solution and a multi-shift solution. The solutions can be obtained by careful examination of either Figure 24 or Table 25. Throughout, the multi-shift total combined cost function lies below the single-shift function.

The iterative approach solutions are remarkably similar to the combinations approach solutions. In fact, the single-shift solution is precisely the same; the same number of plant locations is selected by the model, 29, and they are the same locations. Consequently, the results of Table 26 and Figure 22 apply -- along with attendant explanations. As before, the minimized total distribution, total manufacturing and total combined costs were $21,483,200, $18,193,952 and $39,677,152. The respective average costs were $6.12, $5.18 and $11.30 per ton of estimated feed demand.

The iterative approach's multi-shift solution did differ from that of the combinations approach. In each, the solution was composed of 25 plant locations. But some of the locations were different. While Ames and Centerville were included in the combinations approach solution, they were excluded in the iterative approach solution. Instead, Charles City and Indianola were included. Therefore, the pattern of which plant locations should serve which counties differed. Table 28 and Figure 25 present the results.

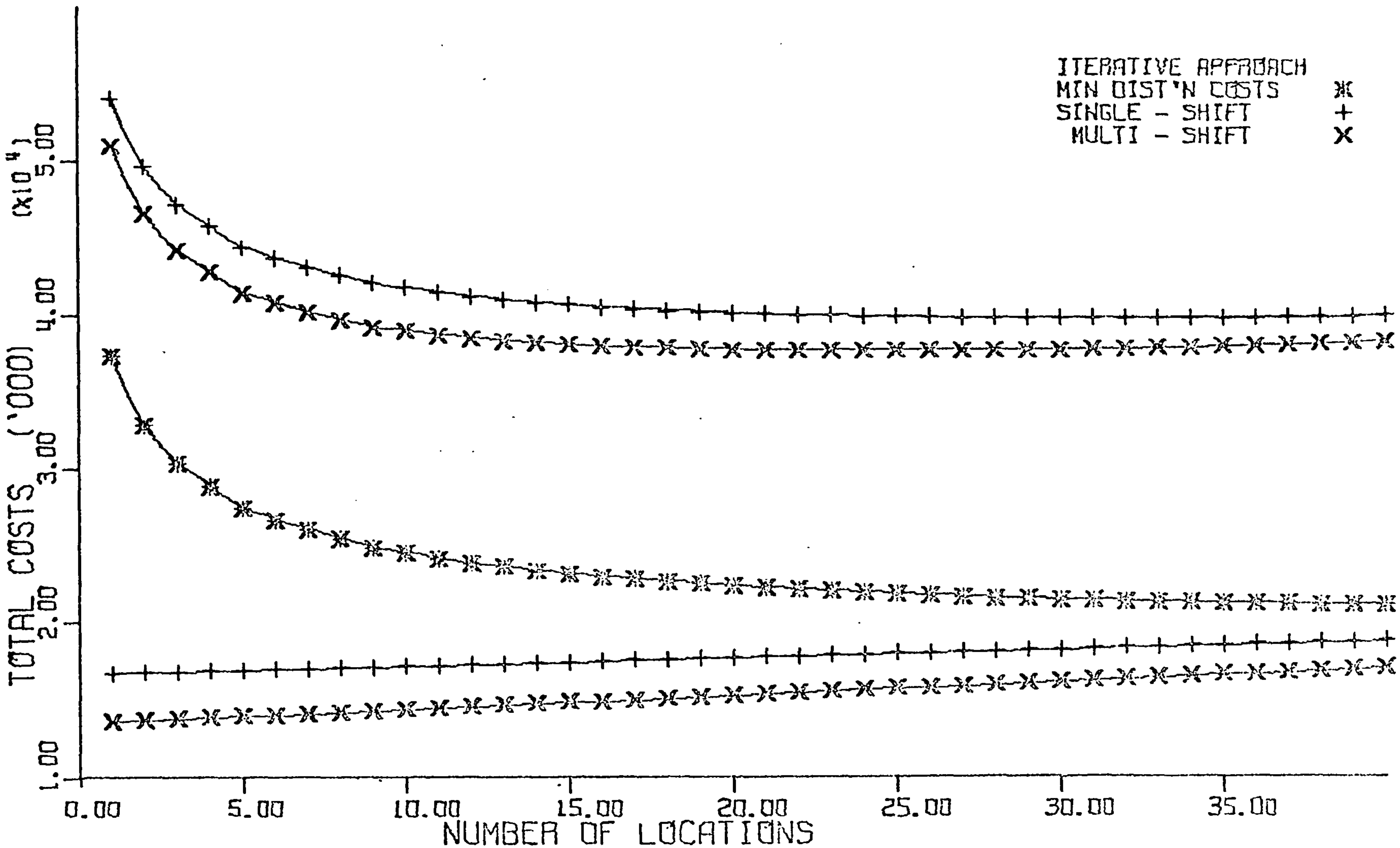

Figure 24. Iterative approach total combined cost functions, single-shift and multi-shift operations

Table 28. Multi-shift iterative approach: 25-plant solution locations, counties served by each, estimated feed tonnage per county and tonnages to be manufactured at each plant location

Location number	Location name	Counties served	County tonnages	Location tonnages
1	Algona	Humboldt	24,178	
		Kossuth	59,280	
		Palo Alto	28,567	
				112,025
2	Atlantic	Audubon	36,501	
		Cass	33,826	
		Harrison	23,057	
		Pottawattamie	58,177	
		Shelby	43,279	
				194,840
3	Burlington	Des Moines	20,634	
		Lee	22,313	
		Louisa	22,319	
				65,266
4	Carroll	Calhoun	28,633	
		Carroll	51,763	
		Crawford	51,010	
		Greene	27,519	
		Guthrie	27,335	
				186,260
5	Cedar Rapids	Benton	56,975	
		Jones	48,824	
		Linn	42,802	
				148,601
6	Charles City	Chickasaw	34,459	
		Floyd	31,977	
		Mitchell	37,253	
				103,689
7	Clarinda	Fremont	12,741	
		Mills	18,978	
		Montgomery	24,988	
		Page	29,358	
		Taylor	20,365	
				106,430
8	Creston	Adair	31,053	
		Adams	19,881	
		Decatur	12,037	
		Ringgold	16,195	
		Union	15,658	
				94,824

Table 28. (Continued)

Location number	Location name	Counties served	County tonnages	Location tonnages
9	Davenport	Clinton	60,715	
		Muscatine	30,553	
		Scott	42,421	
				133,689
10	Decorah	Allamakee	31,265	
		Howard	28,080	
		Winneshiek	50,068	
				109,413
11	Dubuque	Delaware	58,866	
		Dubuque	49,632	
		Jackson	37,234	
				145,732
12	Fairfield	Davis	13,203	
		Henry	34,746	
		Jefferson	19,716	
		Van Buren	16,156	
		Wapello	14,337	
				98,158
13	Indianola	Clarke	15,292	
		Dallas	30,562	
		Lucas	14,254	
		Madison	23,046	
		Polk	20,429	
		Warren	22,969	
		Wayne	18,903	
				145,455
14	Iowa City	Cedar	61,225	
		Iowa	46,041	
		Johnson	54,606	
		Washington	62,848	
				224,720
15	Iowa Falls	Franklin	46,304	
		Hardin	44,462	
				90,766
16	Le Mars	Lyon	41,247	
		Monona	22,313	
		Plymouth	75,195	
		Sioux	76,466	
		Woodbury	53,832	
				269,053

Table 28. (Continued)

Location number	Location name	Counties served	County tonnages	Location tonnages
17	Marshalltown	Grundy	40,851	
		Marshall	35,274	
		Story	37,280	
		Tama	51,304	
				164,709
18	Mason City	Cerro Gordo	41,711	
		Hancock	42,927	
		Winnebago	29,011	
		Worth	28,040	
				141,689
19	Newton	Jasper	48,136	
		Poweshiek	36,150	
				84,286
20	Oelwein	Buchanan	39,900	
		Clayton	49,196	
		Fayette	46,395	
				135,491
21	Oskaloosa	Appanoose	11,335	
		Keokuk	43,474	
		Mahaska	44,706	
		Marion	32,307	
		Monroe	10,957	
				142,779
22	Spencer	Clay	30,745	
		Dickinson	18,496	
		Emmet	17,469	
		O'Brien	43,088	
		Osceola	24,316	
				134,114
23	Storm Lake	Buena Vista	44,764	
		Cherokee	44,657	
		Ida	37,888	
		Pocahontas	35,119	
		Sac	44,777	
				207,205
24	Waverly	Black Hawk	41,759	
		Bremer	33,787	
		Butler	42,737	
				118,283
25	Webster City	Boone	34,098	
		Hamilton	56,355	
		Webster	26,707	
		Wright	37,633	
				154,793

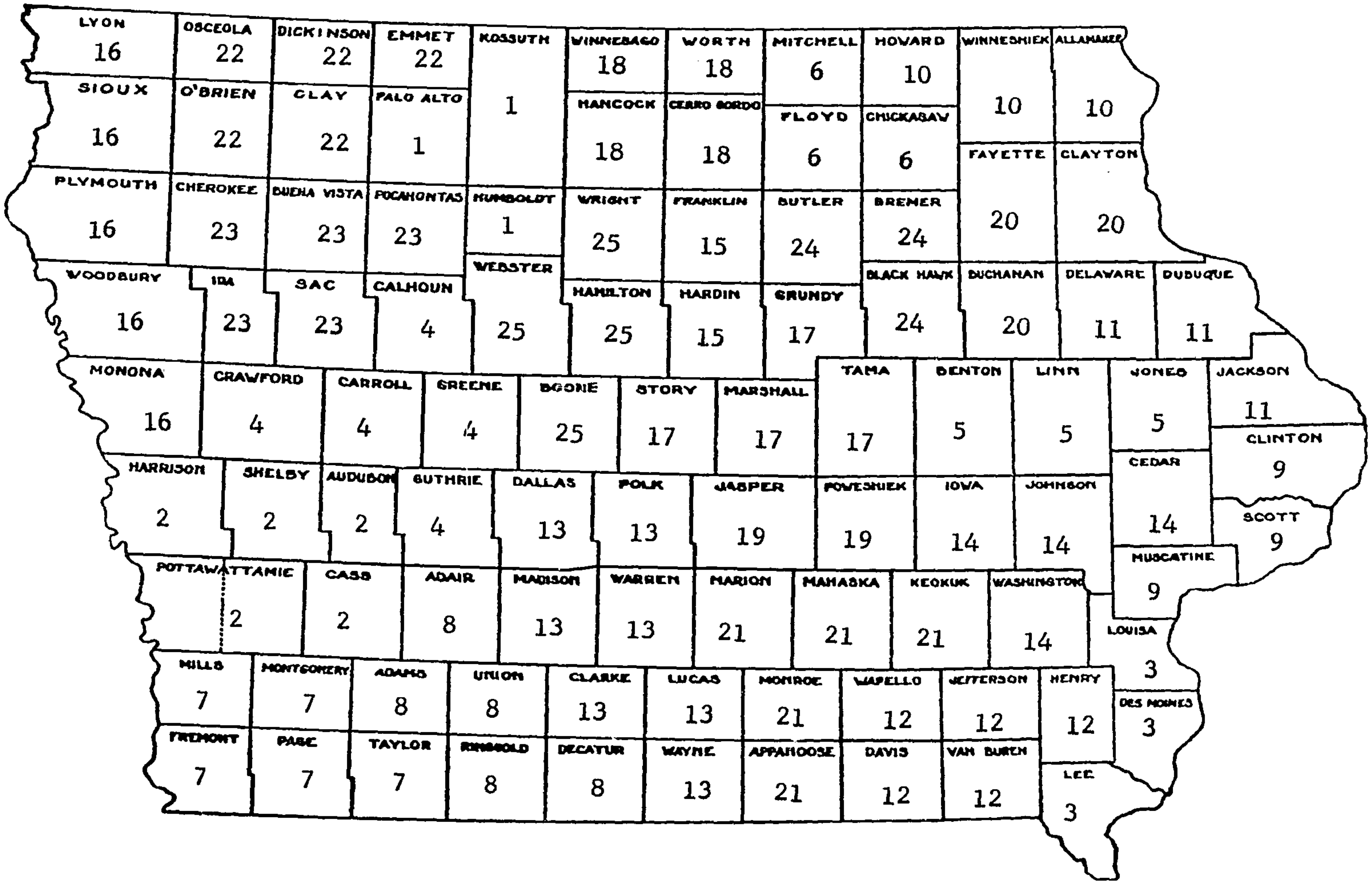

Figure 25. Iterative approach multi-shift solution -- plant locations (by number) supplying feed demand of each county

As would be expected, the minimized total distribution costs were higher for the iterative than combinations approach. The figure was $21,805,664. The multi-shift total manufacturing cost was $15,757,820 and the total combined cost became $37,563,472.[1] The combined average cost was $10.70 per ton -- breaking down into $6.21 and $4.49. The combined average cost for multi-shift was 60 cents per ton lower than single-shift result.

It is interesting to compare the solutions from each major approach followed in the present study. The iterative approach has the practical advantage of being much less expensive to compute. The single-shift solution for each approach was precisely the same. The two multi-shift solutions differed little; that for the iterative approach was only one cent per ton more costly than the combinations approach solution.

D. Implications of the Empirical Results

The author emphasizes that the solution procedures used empirically are suboptimizations. The results cannot be regarded as optimums; not all conceivable location patterns were considered. The iterative approach is a suboptimization procedure because it abides a constraint preventing simultaneous solution of optimum number of plant locations and an optimum location pattern for each number. The combinations approach to solving the long-run spatial model did find the optimal location patterns for the alternatives which were computed. However, computational costs prevented the

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[1]The seventh and eighth digits do not total because of rounding error.

consideration of all conceivable alternatives. In the suboptimization procedure a plant location which was eliminated by the model in two successive steps was eliminated permanently; the optimization might have required the re-entry of some of these plant locations.

The large size of the problem in the present study made optimization of the long-run spatial model computationally infeasible. There could have been two fortuitous exceptions. If the solution number of plant locations had been very small or very large (near 40), optimization could have been achieved. Such was not the case in the present study. The single-shift solution was a set of 29 locations while 25 locations comprised the multi-shift solution. It would have been exceedingly useful to compute $40C_{29}$ and $40C_{25}$ as a check on the suboptimization results. Unfortunately, even these two computational steps were too expensive to be undertaken. It was estimated that computing $40C_{29}$ would require more than 10,000 hours of computer time! Computing $40C_{25}$ would cost even more. Even if the estimate were off by 100 percent (no doubt the variance is high), the computation cost would be far too high.

The solution procedures were written by the author in BPS FORTRAN IV for the IBM 360/50 computer. It is not claimed that the programs written were efficient in a programming sense. But the order of possible improvement in BPS FORTRAN IV might be only 10 to 20 percent -- relatively insignificant in a context of the model's computational requirements. Another possibility for improvement lies in programming by Operating System (OS); execution is much faster but the compile time is very high. Compile time can be obviated once the program is operative but slow compilation makes "debugging" very expensive. There are other problems too. In fact, OS is recommended only for programs which are both long in execution time and will be used very frequently. Even by executing 10 to 20 times as fast, a large problem would remain computationally infeasible. The basic need is for a programming procedure which can consider all combinations without executing all computations. Such a procedure seems to be possible but has not been developed.

While the solutions must be categorized as suboptimum, it is possible that they are optimum. However, the problem of testing the solutions for optimality remains unresolved. The results do seem reasonable.

The productive feed industry activities covered in the present study include distribution costs and manufacturing costs. Distribution costs include both transportation and selling activities. Analysis required an extensive transportation matrix as well as transportation and selling cost information. The manufacturing cost information was developed for single-shift (one day shift) and multi-shift (a day and a night shift) operations. The specific activities included purchasing, ingredient handling, processing, mixing, pelleting and warehousing. For each activity, the cost levels used were normative in the sense of aligning with industry cost standards thought to be attainable. Implications drawn should recognize the normative connotation of the cost results. There are feed industry costs which are not included in the long-run spatial model's analysis; costs of ingredients and research and development costs are examples. Certain locations might offer cost economies not reflected in the model. Business decisions based on model results ought to be tempered by ad hoc considerations relevant to a particular potential plant location.

The cost results for the four solutions are summarized in Table 29. Both total and per ton costs are included. Three major Iowa population centers are excluded from all solutions: Des Moines, Waterloo and Sioux City. There are at least two important reasons why these centers might be included in practical locations for the Iowa feed industry. They are large population centers which might offer important external economies in financing, sales promotion and growth opportunities by either diversification or integration. Ingredient cost advantages likely prevail because of the location of meat packing plants, oilmeal processors and other ingredient suppliers. The model does not consider these cost economies.

Recall that the single-shift solution was the same for both the combinations and the iterative approaches. A set of computations was performed to test the sensitivity of the solution to cost considerations not included in the model. Newton was replaced by Des Moines, Le Mars was replaced by Sioux City and Waterloo replaced Waverly. The resultant increase in per ton cost was small, from $11.30 to $11.35. Of course, the cost increase source was minimized distribution cost with respect to location pattern. The three replacements

Table 29. Summary of cost results for four empirical solutions to the long-run spatial model

	Total costs[a]			Per ton costs		
	Minimized distribution	Manufacturing	Combined	Minimized distribution	Manufacturing	Combined
Combinations approach						
Single-shift	$21,483,200	$18,193,952	$39,677,152	$6.12	$5.18	$11.30
Multi-shift	21,788,016	15,757,821	37,545,824	6.20	4.49	10.69
Iterative approach						
Single-shift	21,483,200	18,193,952	39,677,152	6.12	5.18	11.30
Multi-shift	21,805,664	15,757,820	37,563,472	6.21	4.49	10.70

[a]Digits seven and eight may not check due to rounding error.

would result in some rearrangement of which locations should supply which county's feed demand.

Twenty-five locations made up each of the multi-shift solutions. But the set of 25 locations differs between approaches. Therefore, the replacements and computations were performed separately. In addition to the three replacements discussed above, Atlantic was replaced by Council Bluffs. For the combinations approach, the cost per ton rose $0.07 as a consequence of the replacements -- from $10.69 to $10.76. The difference in the iterative approach also was $0.07. The magnitude of these differences is relatively small.

As a practical matter, the industry would likely locate in Des Moines, Sioux City, Waterloo and Council Bluffs as well as other population centers. The loss in distribution efficiency is relatively slight and might be more than offset by external economies and subjective considerations.

As applied, the model biases against population centers near Iowa's borders. For example, Sioux City would likely be a feed supply source for some Nebraska and South Dakota livestock. Only Iowa feed demand is considered in the present study. As a means of counteracting "border effects," the substitutions of Sioux City for Le Mars and Council Bluffs for Atlantic seem even more reasonable. The arbitrary delineation of state boundaries implies a serious limitation of the present study.

In nearly all cases, the tonnage volumes to be produced at plant locations were less than 200,000 tons annually. Thus, the model results would usually imply that there should be one plant at each location. At three locations, Iowa City, Le Mars (or Sioux City) and Storm Lake, two manufacturing establishments might be more realistic. The tonnage to be supplied from each of these three locations exceeds 200,000 tons yearly.

An important implication of the present study is that the iterative approach results parallel those of the combinations approach. In fact, in the range of 28 to 40 plant locations, the results are exactly the same. The respective single-shift solutions are equal. The multi-shift solutions are virtually equal -- the difference is only one cent per ton. If the combinations approach solutions are meaningful, then the iterative approach would appear to be valid. An important difference is that the iterative approach is less expensive to compute. The iterative approach to the long-run spatial model solution would appear to have important business applications.

How valid are the suboptimum solutions computed in the present study? The question can be resolved only by computing $40C_{29}$, $40C_{25}$ and other combinations in their respective neighborhoods. The cost burden made these computations infeasible. However, the shapes of the estimated cost functions suggest that the degree of suboptimization may be slight. In the neighborhood of the solutions, the total combined cost functions are very flat. This means that a small deviation from the solutions, either by the incorrect number of plant locations or incorrect location patterns, will raise costs only modestly.

The solutions seem to be "robust." It appears doubtful that the optimization procedure (if it could be computed) would reach a solution substantially different from the suboptimization solutions developed in the present study.

The flat configurations of the total combined cost functions have other implications. Since deviation from the solution does not appear to raise costs sharply, factors specific to the location being considered become more important. These factors might be external economies or diseconomies (as discussed earlier), feed ingredient availability or purely subjective in nature. The results infer that feed firms might tend to locate plants either in larger population centers or near related operations such as meat packing plants or soybean oilmeal processors.

Some additional situations were investigated using the model. How much cost efficiency would be sacrificed if plants were located only in Iowa's larger population centers? Suppose ten centers are selected: Cedar Rapids, Council Bluffs, Davenport, Des Moines, Dubuque, Fort Dodge, Mason City, Ottumwa, Sioux City and Waterloo. When the populations of eastern Iowa river cities are discounted somewhat, the selected ten represent Iowa's largest population centers. Table 30 shows the cost results of supplying the 99 counties' estimated feed needs from the ten selected population centers. Comparison with Table 29 results reveals that the ten-location costs exceed the solution costs by important magnitudes. With single-shift operations the per ton combined costs are 89 cents higher; the difference is 71 cents

Table 30. Total and per ton costs for serving Iowa's estimated feed demand from ten selected plant locations

Cost item	Total costs[a]	Average costs
Distribution	$25,621,808	$ 7.30
Single-shift manufacturing	17,183,104	4.89
Multi-shift manufacturing	14,406,856	4.10
Single-shift combined	42,804,912	12.19
Multi-shift combined	40,028,656	11.40

[a]Digits seven and eight may not check due to rounding error.

for multi-shift operations. Clearly, any criteria resulting in selection of the ten-location set chooses poorly; an inefficient location pattern results.

Substantial improvement results from adding five more population centers: Ames, Burlington, Carroll, Iowa City and Marshalltown. The criterion for selection parallels that for the original ten-site set. The 15-location set's cost results make up the content of Table 31.

Table 31. Total and per ton costs for serving Iowa's estimated feed demand from 15 selected plant locations

Cost item	Total costs[a]	Average costs
Distribution	$24,413,392	$ 6.95
Single-shift manufacturing	17,449,120	4.97
Multi-shift manufacturing	14,857,181	4.23
Single-shift combined	41,862,512	11.92
Multi-shift combined	39,270,560	11.18

[a]Digits seven and eight may not check due to rounding error.

Although the additional five plants imply improved cost efficiency, the 15-location combined costs exceed the combined costs of the long-run spatial model's solutions. The magnitudes of the differences are important. Single-shift solution combined costs were 62 cents per ton lower. Meanwhile, multi-shift solution combined costs improved on the corresponding 15-site costs by 49 cents. This location set, chosen largely on the basis of population size, does not result in an efficient industry location pattern.

In the iterative approach costs were computed for 10- and 15-location sets. For ten sites, the per ton combined costs of the iterative approach were 33 cents lower than the costs for the previously selected set of ten locations. The differences were the same for both single- and multi-shift operations, that is, 33 cents. Comparing for 15 locations, the results were similar inasmuch as the solution costs were 27 cents per ton lower for both single- and multi-shift operations. The cost differences indicate a need for more complex choice criteria than simply to locate feed manufacturing plants in large population centers.

It would be very useful to compare the model solutions with the existing situation in the Iowa feed industry. A detailed description of the Iowa feed industry is needed. A limitation of the present study is that complete descriptive information is lacking; the problems encountered here are discussed in the next chapter. However, a reasonably good description could be obtained from the American Feed Manufacturers' Association (AFMA) list of plant locations in Iowa. The AFMA list was supplemented by Midwest Feed Manufacturers' Association (MFMA) information and personal knowledge.

Major feed-manufacturing plants were discovered in at least 26 Iowa locations. These are listed in Table 32. Using the 26 locations, the long-run spatial model was used to find the cost-minimizing distribution pattern. Each location would supply two or more counties. The specific location-to-county relationships are outlined in Table 32 and illustrated in Figure 26.

The cost results are presented in Table 33. The costs pertain to an approximate location description of the Iowa feed industry. Compare Table 33 with Table 29. The long-run spatial model's location configuration solution results in lower combined costs than the existing situation as approximated. For single-shift operations the potential savings could be 25 cents per ton; potential savings for the multi-shift alternative could be 24 cents per ton. The magnitude of these potential savings seems important. Expressed in terms of the estimated feed demand for Iowa, 3,512,269 tons, the potential savings could be nearly one million dollars. If single shifts were operated, the potential savings could be $878,067; for multi-shift operations the figure would be $842,945.

The number of known plant locations corresponded closely to the number suggested by model solutions. But the existing location pattern was not optimum. No doubt there are a few plants which remain undetected in the present study. Among the 26 locations there were more than 40 plants. Fewer plants would exist if model solution results were followed. As a consequence of comparing the existential situation with model results, two implications appear

Table 32. Approximate existing situation: 26 locations, counties served by each, estimated feed tonnagesper county and tonnages to be manufactured at each plant location

Location number	Location name	Counties served	County tonnages	Location tonnages
1	Ames	Boone	34,098	
		Greene	27,519	
		Marshall	35,274	
		Story	37,280	
				134,171
2	Atlantic	Adair	31,053	
		Adams	19,881	
		Audubon	36,501	
		Carroll	51,763	
		Cass	33,826	
		Guthrie	27,335	
		Montgomery	24,988	
		Page	29,358	
		Shelby	43,279	
		Taylor	20,365	
				318,350
3	Cedar Rapids	Benton	56,975	
		Jones	48,824	
		Linn	42,802	
				148,601
4	Centerville	Appanoose	11,335	
		Decatur	12,037	
		Ringgold	16,195	
		Wayne	18,903	
				58,470
5	Charles City	Allamakee	31,265	
		Butler	42,737	
		Chickasaw	34,459	
		Floyd	31,977	
		Howard	28,080	
		Mitchell	37,253	
		Winneshiek	50,068	
				255,839
6	Cherokee	Cherokee	44,657	
		Ida	37,888	
		O'Brien	43,088	
				125,633
7	Council Bluffs	Fremont	12,741	
		Harrison	23,057	
		Mills	18,978	
		Pottawattamie	58,177	
				112,953

Table 32. (Continued)

Location number	Location name	Counties served	County tonnages	Location tonnages
8	Davenport	Clinton	60,715	
		Scott	42,421	
				103,136
9	Des Moines	Dallas	30,562	
		Jasper	48,136	
		Polk	20,429	
				99,127
10	Dubuque	Dubuque	49,632	
		Jackson	37,234	
				86,866
11	Estherville	Emmet	17,469	
		Kossuth	59,280	
				76,749
12	Fort Dodge	Calhoun	28,633	
		Hamilton	56,355	
		Humboldt	24,178	
		Webster	26,707	
				135,873
13	Independence	Buchanan	39,900	
		Clayton	49,196	
		Delaware	58,866	
		Fayette	46,395	
				194,357
14	Indianola	Clarke	15,292	
		Lucas	14,254	
		Madison	23,046	
		Union	15,658	
		Warren	22,969	
				91,219
15	Iowa City	Cedar	61,225	
		Iowa	46,041	
		Johnson	54,606	
				161,872
16	Iowa Falls	Franklin	46,304	
		Hardin	44,462	
		Wright	37,633	
				128,399
17	Le Mars	Lyon	41,247	
		Plymouth	75,195	
		Sioux	76,466	
				192,908

Table 32. (Continued)

Location number	Location name	Counties served	County tonnages	Location tonnages
18	Mason City	Cerro Gordo	41,711	
		Hancock	42,927	
		Winnebago	29,011	
		Worth	28,040	
				141,689
19	Muscatine	Des Moines	20,634	
		Louisa	22,319	
		Muscatine	30,553	
				73,506
20	Oskaloosa	Keokuk	43,474	
		Mahaska	44,706	
		Marion	32,307	
		Poweshiek	36,150	
				156,637
21	Ottumwa	Davis	13,203	
		Jefferson	19,716	
		Monroe	10,957	
		Van Buren	16,156	
		Wapello	14,337	
				74,369
22	Sioux City	Monona	22,313	
		Woodbury	53,832	
				76,145
23	Spencer	Clay	30,745	
		Dickinson	18,496	
		Osceola	24,316	
		Palo Alto	28,567	
				102,124
24	Storm Lake	Buena Vista	44,764	
		Crawford	51,010	
		Pocahontas	35,119	
		Sac	44,777	
				175,670
25	Washington	Henry	34,746	
		Lee	22,313	
		Washington	62,848	
				119,907
26	Waterloo	Black Hawk	41,759	
		Bremer	33,787	
		Grundy	40,851	
		Tama	51,304	
				167,701

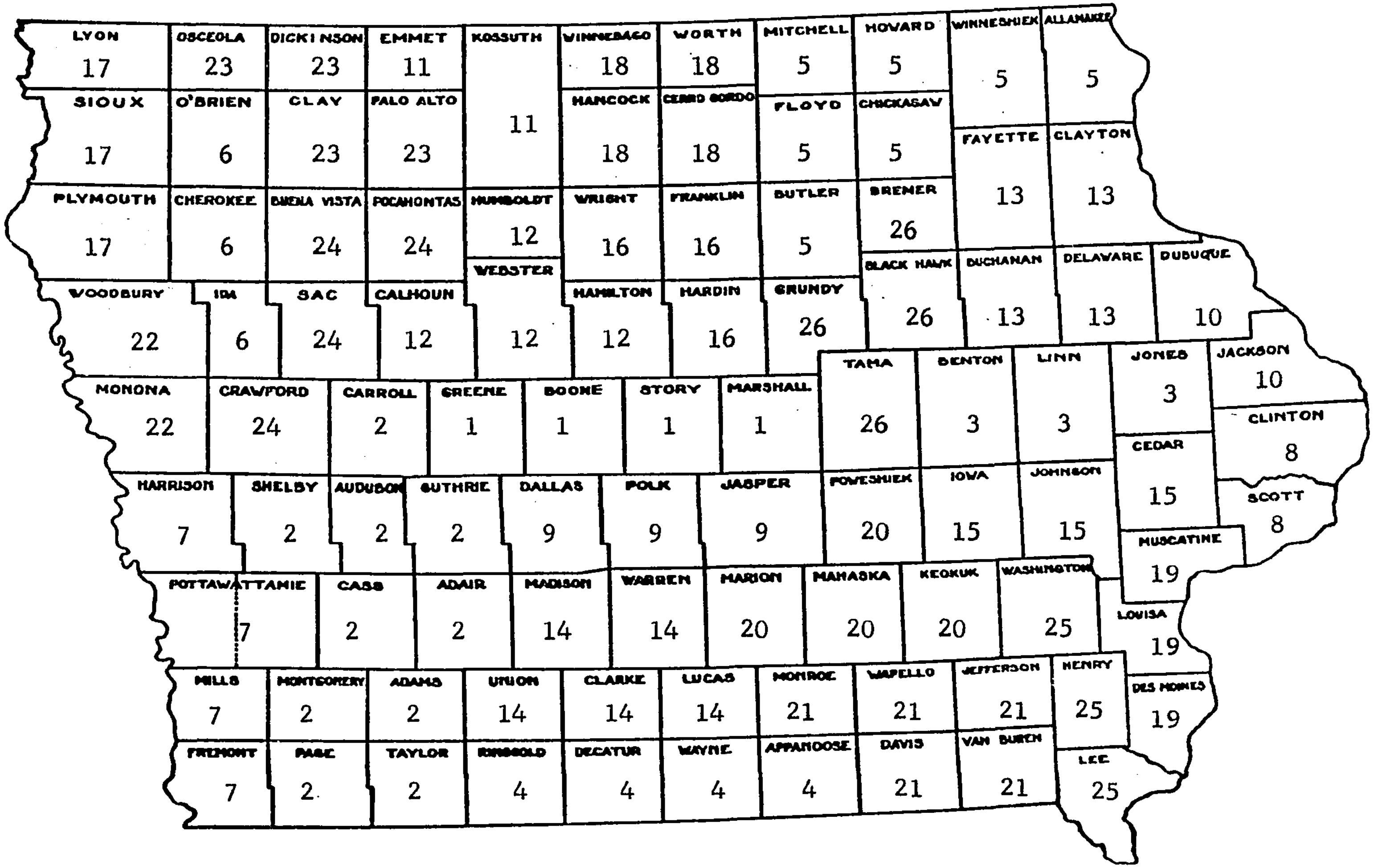

Figure 26. Approximate existing situation -- plant locations (by number) to supply feed demand of each county

to hold. First, the Iowa feed industry may be overbuilt in terms of the number of plant locations. Second, over-all feed industry costs might be lower if there were fewer plants in some locations.

Table 33. Total and per ton costs for serving Iowa's estimated feed demand from an approximation of the existing situation

Cost item	Total costs[a]	Average costs
Distribution	$22,526,512	$ 6.42
Single-shift manufacturing	18,034,336	5.13
Multi-shift manufacturing	15,847,882	4.51
Single-shift combined	40,560,848	11.55
Multi-shift combined	38,374,384	10.93

[a]Digits seven and eight may not check due to rounding error.

The translation of model results into individual firm behavior is not clear. Even though the industry as a whole might have excess facilities, the rational expansion of an individual firm is not precluded. Unless an existing facility is very badly located, it will not be eliminated instantaneously. A facility will usually be phased out by "depreciating it out" -- economic theory suggests continued operation of a facility as long as returns exceed variable costs. The long-run spatial model assumes that the feed demand of each county is the monopoly of some plant location. In reality, there is competition. Individual firms have a cost motivation to conform to an over-all industry cost-minimizing locational pattern; profit-maximization objectives, in the context of a competitive framework, may prevent optimum industry location. The reconciliation of profit-maximization and cost-minimization objectives has never been fully accomplished in economic theory.

Increased competition would be expected to raise over-all industry costs above the levels suggested in solutions of the present study. On the other hand, economic theory indicates that not all cost savings will be "passed along" if individual firms are free to pursue monopoly-pricing policies. From the feed purchasers' point of view, the "cost of competition" can be less than the "cost of monopoly pricing." In general, the location pattern results of the present study suggest that the Iowa feed industry cost performance is acceptable. Therefore, it would appear that immediate and stringent public policy action is not necessary.

In a context of public policy, feed industry production and distribution efficiency should be an important objective. Results of the present study do not indicate a need for strong public policy measures to ensure an efficient location pattern for the commercial mixed-feeds industry. On the other hand, public policy objectives could emphasize regional development. By encouraging the construction of feed manufacturing plants in regions where development is badly needed, important social objectives might be achieved with relatively minor sacrifices in economic efficiency.

The implications drawn in this section refer to the solutions computed in the present study. The solutions involve large numbers of plants. In many research problems only a few plants would comprise the solution. Should this be the case, the combinations and iterative approach results would differ more substantially. The iterative approach results would be less reliable. In addition, any deviation from the solution would be more serious.

VIII. LIMITATIONS OF THE PRESENT STUDY

It is important to recognize the limitations of any research effort. Such recognition guides the interpretation of results and enables one to suggest ideas for future research. It will be the purpose of this chapter to recognize some of the present study's major limitations. At the same time, some suggestions for further research will be made.

The limitations of the present study fall into two general categories. One is the degree of sophistication and precision with which the data requirements of the model were developed. The limitations inherent in the long-run spatial model form the second category. In the first category any further research suggestions largely refer to the need for more reliable data inputs and more painstaking data development. However, limitations inherent in the model open some important research horizons.

In the present study, two approaches were used to solve the long-run spatial model -- dubbed the combinations approach and the iterative approach. Each is a suboptimization. When applied to large problems, a serious limitation of the model is its computational requirements for an optimization solution. The limitation is much less severe for small problems. The suboptimization solutions of the present study seem reasonable and probably differ little, if any, from the unknown optimization solution. The application of the long-run spatial model to large problems affords an opportunity for the computer science discipline to make an important contribution.

Given that the suboptimizations differ little from what would be the optimum solution, the results can be useful as a guide to future development of the feed industry. The model's solution can be considered as a static equilibrium situation dependent upon available technology. These research results should abet industry leaders and potential investors by showing where savings can be realized for the industry as a whole. Feed producers whose manufacturing establishments conform to the industry optimum location pattern should accrue savings, enhancing their ability to compete. Thus individual firms (or cooperatives) would have an incentive to reach the industry optimum. However, the mechanism by which individual firms would be expected to conform to the solution is not entirely clear. A theoretical addendum to the model is needed to consider how the industry should become optimally patterned. A part of this extension should be integration with available research results concerning retail feed distribution. The present study analyzes the Iowa feed industry at the "wholesale" level of feed distribution.

A shortcoming of the model and its solution(s) is its failure to consider the effect of competition among firms. This competition could alter the solution. For example, one would not expect selling costs to be independent of the level of competition. In fact, the model implicitly assumes that each county's feed tonnage demand is monopolized by one plant location. Competition within counties would probably increase costs. The severity of this shortcoming could be alleviated a great deal by developing feed demand estimates at the township level rather than county level of disaggregation. Such a procedure would increase the computational burden sharply. If there was an average of 25 townships per county, in Iowa, data for 2,475 feed demand estimates would be needed instead of only 99.

Another shortcoming is that "border effects" are not considered explicitly. The solution results are biased against including plant locations near the state borders. The border effects would have been much more serious had solution(s) consisted of only a few plants. The bias is more serious where state boundaries do not follow natural barriers to transportation. Qualitatively it is clear that non-Iowa feed demand should be included for some potential plant locations. If the non-Iowa demand were quantitatively overestimated, population centers near the border could dominate the solution. In the case of Estherville, for instance, Minnesota feed plants would compete not only for Minnesota feed demand but for some of Estherville's Iowa feed demand. One way to consider non-Iowa demand formally would be as follows: obtain a solution ignoring border effects, use the pattern of solution results as a basis for formal inclusion of non-Iowa demand and then re-estimate the long-run spatial model's solution.

A conceptual extension of the model could include ingredient assembly costs and alternative organizational patterns for distributing feed. A feed manufacturing plant located adjacent to a soybean processing plant and/or a meat packing plant would be expected to realize some ingredient assembly cost economies. In states or regions where carbohydrate sources are deficit rather than surplus, feed grain assembly cost economies could be very important. Full development of high-lysine corn production could affect optimum location solutions for the feed industry. The marketing organization assumed for the present study is rigid. It follows the traditional pattern of feed distribution where feed is sold from the manufacturing establishment to retail feed distributors or large commercial users. The feed retailers would then sell to smaller feeders and farmers. There are alternative methods -- some are being tried in the feed industry today. A feed company might manufacture premixes in a large centralized plant and distribute to its own smaller decentralized feed manufacturing plants. These plants could manufacture complete feeds and supplements as well as custom-mix specialty feeds. The long-run spatial model could be applied to each of several marketing organization patterns (or some combinations of them) -- seeking further industry cost-reduction possibilities.

The effectiveness of any model can be enhanced by increasing the precision of its data input requirements. Hence, each data input is a limitation; some are more serious than others. The county feed demand estimates of the present study were computationally laborious. Yet they are not sophisticated in the sense of statistical estimation. Improvement in demand estimates is a major possibility for improvement of this research. *A fortiori*, statistical analysis provides a basis for projections and some indication of the variation to be expected.

The author feels the transportation matrix results developed for the present study are sound. The transportation cost results appear to be reasonable although the estimates could be used more confidently if they were based upon a larger sample. The selling cost estimates are open to some doubt. The data available on this cost source are scant. Additional research in this area is needed to alleviate the dearth of selling cost information for the feed industry.

It is felt that the feed manufacturing cost estimates represent a competent synthesis of the gamut of pertinent cost information. Nevertheless, complete information on feed manufacturing costs in Iowa was unavailable. In the cost synthesis, chronological and regional adjustments were made in order to describe feed manufacturing cost results reasonably representative of Iowa. It would be very helpful to have had comprehensive cost analysis results pertaining to the Midwest -- Midwest results should represent Iowa reasonably well, and vice versa.

A useful step in the present study's research was to compare its solution results with the Iowa feed industry's existing situation. However, a study limitation is that a more detailed and precise industry description is needed. More specific cost-saving possibilities should become identifiable. A detailed description of the Iowa feed industry is a more demanding task than it would first appear. Much of the needed information is confidential in nature. Obtainable lists have no guarantee of completeness. Moreover, they do not stratify the industry entities; classification by size would be most helpful. Some survey work in the industry, in consultation with industry leaders, would likely be necessary to establish a reliable description of the Iowa feed industry. A complete description would permit comparisons with model solution results. This research remains as a logical next step.

The results of the present study could be duplicated for time periods in the past and for projections into the future. Parallel model applications to the 1950, 1954 and 1959 Censuses of Agriculture would establish a time series of long-run spatial model solutions. Accurate Iowa feed industry descriptions for 1950, 1954, 1959 and 1964 would enable the researcher to detect whether the industry has been moving toward the cost-minimization patterns suggested by model solution results. Projections could be made for feed demand and for technology affecting feed manufacturing and transportation. The model could be applied using projection data as numerical inputs. The solutions should afford a guide toward over-all Iowa feed industry economic efficiency.

IX. SUMMARY AND CONCLUSIONS

Important changes have taken place in American agriculture. These changes have been particularly rapid and important in the last two decades. As a leading agricultural state, Iowa has exemplified many changes. The term commercialization has been used to encompass numerous trends in agriculture. This term implies that agriculture has been redirected from highly diversified to more specialized production, that the interdependence between agriculture and non-agricultural sectors has strengthened and that farmers have become more price-conscious while demanding more services with their purchases. Farms have become fewer in number but larger in size. An increasing proportion of farm production inputs have become non-agricultural in source.

Important changes in the feed industry have materialized as a consequence of scientific nutritional advances and changes in agriculture. The feed industry, formerly expected to supply only protein supplements, has become a supplier of services, technical knowledge and complete feeds as well. The demand for commercial mixed-feeds has risen more rapidly than the aggregate demand for livestock feed. The feed industry has expanded both in output volume and in the nature of its product.

A general objective of the present study was to supply information and methodology by which the economic efficiency of the Iowa feed industry could be improved. The primary focus was on efficiency with respect to location. The research objective can be stated in the form of a formal hypothesis. It was hypothesized that over-all Iowa feed industry costs could be reduced by solving a long-run spatial model for an optimum locational configuration. In order to test the hypothesis, the data requirements of the long-run spatial model had to be developed. As a by-product of the primary research objective, the Iowa feed industry should be able to glean useful information from the data developed in the present study.

A feed tonnage estimate was made for each of Iowa's 99 counties. The 1964 Census of Agriculture was the foundation for these estimates. For Iowa, it was estimated that 3.5 million tons should be supplied by the commercial mixed-feeds industry. Within each county, the feed tonnage estimates were disaggregated into estimates for each of 16 major livestock classes. Further, each estimate was separated into supplement and complete feed tonnages. The number of feed tonnage estimates totaled 3,168. An important data set was a road mileage transportation matrix for Iowa. It was used, in conjunction with transportation cost and selling cost analysis, to obtain a distribution cost matrix. Finally, feed manufacturing costs representative of Iowa were ascertained. Single-shift and double-shift (a special case of multi-shift) operations were analyzed. Economies of scale were detected for each. The respective total cost functions were found to be linear.

The present study's long-run spatial model was solved in accordance with county demand estimates and a set of potential plant locations in Iowa. The procedure consisted of simultaneously computing points on three total cost functions; each function was related to number of plant locations. Total distribution costs were minimized with respect to locational pattern. Resultant tonnages at included locations were used to estimate total manufacturing costs. The sum of the two previous costs formed total combined costs. The minimum point on the total combined cost function was the model's solution. Operationally, the optimization could not be calculated because the computational cost burden would have been excessive. Two sub-optimal solution procedures were programmed on the IBM 360/50 computer: combinations approach and iterative approach. The nature of the computed suboptimizations indicated that optimization was approximated closely.

The total cost relationship with volume processed was linear for the individual plant. The consequence of this empirical result was that the total feed manufacturing cost function with respect to plant numbers was also linear. For each number of plants, distribution costs were minimized with respect to location pattern. The configuration of the resulting minimized total distribution cost function was that of a rectangular hyperbola. Empirical results showed all first differences as negative and all second differences as positive. The summation of the total manufacturing and minimized total distribution cost functions yielded a parabolic total combined cost function -- a convex set. The solutions to the long-run spatial model were found by determining minimum points on the respective total combined cost functions.

For single-shift operations, the two suboptimization solutions were identical. Both the combinations approach and the iterative approach solutions found costs to be minimized with 29 plant locations. The location-to-county relationships were specified. Per ton costs, for activities uncompassed by the model, would be minimized at $11.30 - $6.12 for distribution costs and $5.18 for feed manufacturing costs. These cost levels could serve as an industry benchmark cost standard, especially for feed manufacturing costs. The respective solutions by the combinations and iterative approaches differed only slightly for multi-shift operations (double-shift in the present study). Both approaches reached a solution of 25 plants. But the intersection of the two sets contained only 23 plants -- two differed. Nevertheless, cost results were nearly identical. Combinations approach average combined costs were $10.69. The iterative approach solution was only one cent per ton higher.

When the model was applied using potential plant locations chosen solely on the basis of large populations, inefficient location patterns resulted. Thus the need was seen for explicit spatial analysis. However, when large population centers (excluded from the model's solution) replaced the nearest smaller center (included in the solution), costs rose only slightly. In actual location decisions, firms would likely forego some locational cost efficiency to reap external economies and expansion opportunities which attend location in larger population centers.

When a locational description of the Iowa feed industry was applied to the long-run spatial model, cost-savings possibilities were detected. About 25 cents per ton could be saved by supplying Iowa's feed demand from the locational pattern suggested by the model's solution. At 25 cents per ton, the estimated total annual savings would be nearly one million dollars. Albeit these cost savings may be important on the margin, the magnitude of the savings is small in a context of average distribution costs. Only about one-half of one percent would be saved. Yet, because of investment indivisibilities, even small cost savings achieved through locational efficiency tend to be important. Such savings can be realized over several time periods.

The individual firm could use the model to identify specific cost-saving opportunities. When there are many plants, the iterative approach appears to be particularly useful. It corresponds closely to the individual firm's decision situation and the computing cost is modest.

The long-run spatial model seems useful in testing for industry location efficiency. It can be concluded that entities comprising the Iowa feed industry are located relatively well.

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APPENDIX A. CALCULATED ANIMAL UNITS FOR EACH COUNTY, BY EACH LIVESTOCK VARIABLE

COUNTY	VARIABLE NAME							
	M1COWS	MH2HC	B3COWS	FINV4L	FINV5S	OTH6	H7M	ST8SH
ADAIR	5640	1215	10159	24380	2765	12052	1240	584
ADAMS	3277	706	7087	9308	3834	7194	763	194
ALL KEE	28524	6143	6680	7163	698	10061	1026	191
APP SE	4660	1004	7558	3103	1352	6195	1485	875
AUDUBON	7106	1531	4144	62433	7889	14782	727	294
BENTON	8843	1905	8466	78145	4801	16479	1112	489
B HAWK	15760	3394	2832	45405	1690	7922	1340	1413
BOONE	3215	693	3506	47568	2376	8108	1317	451
BREMER	25122	5410	1308	9993	997	5186	987	156
BUCH N	17556	3781	3524	27505	2518	8094	2586	294
B VISTA	4254	916	3024	57048	2705	8642	640	973
BUTLER	18145	3908	3722	21835	4441	8968	1246	227
CALHOUN	3282	707	4315	35485	7175	7352	1210	460
CARROLL	7807	1682	5932	84473	5440	16592	909	329
CASS	4517	973	7665	57980	6089	13833	1324	303
CEDAR	9954	2144	5802	68620	3710	12654	1137	657
C GORDO	6083	1310	3530	29165	2297	7131	1256	513
CH KEE	5825	1255	3213	115000	1850	17596	1009	431
CH SAW	16955	3651	3704	18565	1377	7877	1288	178
CLARKE	3528	760	7560	3195	2200	6186	892	211
CLAY	5120	1103	3528	59088	3384	9838	944	814
CLAYTON	41758	8993	5432	12330	950	10034	1133	260
CLINTON	13031	2806	4815	124460	2191	20088	1355	249
C FORD	11154	2402	7970	67520	5983	18434	1322	501
DALLAS	3422	737	4859	28668	3463	7558	1130	348
DAVIS	6427	1384	6048	2888	1269	5331	1184	2044
DECATUR	4774	1028	7757	2865	1669	7724	1233	299
D WARE	32783	7060	2175	20413	1582	7800	897	118
DES M S	2459	530	4154	17643	4162	4895	953	296
D INSON	4882	1052	2404	25698	2839	6325	522	711
DUBUQUE	35753	7700	5012	32973	1555	7750	890	109
EMMET	3707	799	2437	29495	3742	5729	575	312
FAYETTE	34777	7490	4062	24118	1381	10671	1228	197

APPENDIX A (CONTINUED)

COUNTY	VARIABLE NAME							
	M1COWS	MH2HC	B3COWS	FINV4L	FINV5S	OTH6	H7M	ST8SH
FLOYD	7820	1684	3186	33665	1701	7010	925	296
FR KLIN	9350	2014	3418	54093	5207	9594	1170	1419
FREMONT	1300	280	3755	32343	2243	6357	661	147
GREENE	2803	604	4373	36893	5116	8033	914	448
GRUNDY	9374	2019	3730	47680	3832	9263	938	646
GUTHRIE	5530	1191	8224	19290	5782	9701	1219	387
HAM TON	2740	590	2210	50080	2813	7281	1389	352
H COCK	8363	1801	2922	40838	1134	7263	868	464
HARDIN	6932	1493	3851	55823	4199	10670	1207	645
HARR N	4991	1075	5144	33953	3740	10751	1025	125
HENRY	2856	615	4489	10558	5222	5168	1427	467
HOWARD	17731	3819	4062	8975	1379	6742	742	207
H BOLDT	4033	869	1668	33640	1930	5951	578	464
IDA	3948	850	3590	75595	4018	14128	666	252
IOWA	7795	1679	10179	46713	2813	14160	1095	531
JACKSON	19619	4225	8686	39965	2954	12882	1375	161
JASPER	10388	2237	8902	46965	7610	12439	1427	497
JEF SON	3290	709	4406	9583	2768	4970	1011	578
JOHNSON	5918	1275	7764	25300	3901	10088	2288	670
JONES	15353	3306	5121	67998	2417	13093	1481	418
KEOKUK	5214	1123	7090	15093	3620	8280	1691	652
KOSSUTH	12640	2722	4926	63303	4867	12887	1291	1002
LEE	6204	1336	4357	17118	2965	5417	1176	560
LINN	14155	3049	5917	38330	1933	10101	1690	733
LOUISA	1387	299	3587	14315	4034	4562	727	244
LUCAS	3101	668	6634	2418	1825	6173	1791	686
LYON	14816	3191	2986	79308	1746	12331	1002	798
MADISON	3412	735	9704	10695	3631	9682	1345	455
MAHASKA	7650	1648	5517	40688	4772	8802	1309	744
MARION	7405	1595	5793	26100	4725	7236	997	1035
M SHALL	6154	1325	6542	64135	6127	12458	1354	551
MILLS	2083	449	2656	50730	1291	6137	654	135
MITCH L	11672	2514	2048	47588	4937	6680	826	250

APPENDIX A (CONTINUED)

COUNTY VARIABLE NAME

	M1COWS	MH2HC	B3COWS	FINV4L	FINV5S	OTH6	H7M	ST8SH
MONONA	3934	847	3562	28100	1584	7934	945	363
MONROE	3047	656	6264	2100	855	5511	1707	608
MONT RY	4026	867	4496	38725	3969	9915	808	209
M TINE	6174	1330	4029	27965	2700	6038	881	241
O BRIEN	8947	1927	2201	73015	2866	10334	965	650
OSCEOLA	8305	1789	1688	40675	1996	7432	316	437
PAGE	3770	812	6335	48260	3677	11319	1116	226
P ALTO	5296	1141	2749	39228	3632	7561	732	374
P MOUTH	8280	1783	6424	128863	4158	19599	1309	519
POC TAS	4193	903	2486	50755	2678	8080	707	483
POLK	4214	908	3534	17658	2956	5410	1429	349
POT WAT	6896	1485	6060	187450	4169	21166	2374	567
P SHIEK	7609	1639	8865	29373	6833	11529	1095	413
R GOLD	4931	1062	8822	7325	1768	8651	1070	236
SAC	6704	1444	5346	92888	5621	15375	820	493
SCOTT	9397	2024	3292	41758	2056	8528	1365	247
SHELBY	8356	1800	4900	81410	7585	16187	1109	189
SIOUX	23557	5073	2119	159123	5310	20681	1061	825
STORY	4514	972	3131	47870	2014	7616	1329	478
TAMA	7819	1684	9317	61278	4851	16322	1022	471
TAYLOR	4980	1073	8818	10695	3980	8894	1623	469
UNION	3270	704	7714	8330	2174	7945	1148	223
V BUREN	3914	843	5950	2870	1134	4807	1355	1173
WAPELLO	3360	724	4659	6465	1530	4720	1266	549
WARREN	6186	1332	7400	5903	5198	7450	1326	286
WASH N	3686	794	4924	26145	3314	7000	1235	538
WAYNE	6292	1355	8929	5533	2212	7779	1425	399
WEBSTER	3272	705	3964	21493	4905	5874	1525	299
W BAGO	7411	1596	1844	15343	680	4286	554	196
W SHIEK	37105	7991	6756	12580	1319	12410	1274	277
W DBURY	6203	1336	5543	109060	3213	16461	1564	614
WORTH	6023	1297	2170	22375	1001	4400	608	300
WRIGHT	4976	1072	2726	30675	4194	6973	1394	614

APPENDIX A (CONTINUED)

COUNTY	VARIABLE NAME							
	FD9SH	C10OLD	T11BR	SW12BR	BR13	OC14SL	TUR15R	HOG16S
ADAIR	642	10924	1	14114	0	2185	143	145165
ADAMS	213	5538	0	9713	0	1188	7	99702
ALL KEE	210	7641	0	12214	32	1672	5848	131837
APP SE	961	2919	1	5321	0	499	10	53799
AUDUBON	322	16407	8	13521	25	3719	434	139989
BENTON	537	15044	0	25052	33	3831	770	266866
B HAWK	1552	14511	392	13895	10	3596	12504	161004
BOONE	495	19306	14	11432	16	4372	4619	126212
BREMER	171	18400	211	10919	17	4084	9307	115935
BUCH N	323	14759	75	15812	9	3027	3552	174965
B VISTA	1069	12278	511	17627	0	2582	16051	185288
BUTLER	249	21341	71	17334	61	5164	4237	171860
CALHOUN	506	9615	368	11609	18	2310	6044	116255
CARROLL	362	16798	0	22259	19	4020	5682	214171
CASS	333	10474	0	14285	0	2836	350	143441
CEDAR	722	9479	1	29210	0	2353	46	319814
C GORDO	564	17177	889	17917	80	3921	15010	163452
CH KEE	474	8754	313	16630	69	2320	8636	172233
CH SAW	196	18643	294	11297	72	3361	6931	128921
CLARKE	232	2507	0	6608	8	433	6435	69599
CLAY	894	11195	1	12049	13	3056	317	123871
CLAYTON	286	13548	103	23032	36	2822	923	224323
CLINTON	273	10690	13	24629	0	2267	43	279592
C FORD	551	18653	1	23114	0	4917	2630	211867
DALLAS	382	9239	24	13241	22	2749	2665	142678
DAVIS	2246	3979	15	5856	410	1348	5	57679
DECATUR	328	2172	0	4997	0	204	3080	54744
D WARE	130	21402	35	28924	0	3821	7	275594
DES M S	325	3754	0	9632	664	837	106	104167
D INSON	781	9065	210	6887	0	2942	1895	64854
DUBUQUE	119	12097	0	22610	1099	2729	125	223983
EMMET	343	6289	154	6448	80	1907	1954	66194
FAYETTE	217	20404	135	16732	60	4831	2970	184910

APPENDIX A (CONTINUED)

COUNTY	VARIABLE NAME							
	FD9SH	C10OLD	T11BR	SW12BR	BR13	OC14SL	TUR15R	HOG16S
FLOYD	326	14140	326	9614	194	3886	12541	111830
FR KLIN	1560	19395	113	19724	48	4766	7159	184159
FREMONT	161	1790	0	5147	0	335	701	53765
GREENE	492	6985	14	11796	0	1672	3594	123354
GRUNDY	709	13747	168	15953	0	2812	5187	177824
GUTHRIE	425	12716	0	11311	8	3209	0	117353
HAM TON	386	8309	722	14386	31	2284	77088	154318
H COCK	510	25251	319	16079	34	6820	8386	154281
HARDIN	709	13362	65	19357	0	3321	9168	188452
HARR N	137	4861	3	10538	0	1297	8	105466
HENRY	513	3999	837	13270	53	1020	27906	143723
HOWARD	228	17696	11	9578	164	3984	1835	102170
H BOLDT	509	10004	1	10951	0	3397	1125	97706
IDA	277	10413	990	14954	0	2115	9317	144649
IOWA	584	7974	347	20848	0	1902	10874	213443
JACKSON	177	6434	29	16287	0	1098	9	176187
JASPER	546	12572	0	21077	50	3123	893	231160
JEF SON	635	4075	7	8880	0	939	1016	103094
JOHNSON	736	8564	383	23412	0	1698	26811	252313
JONES	459	9682	1	22811	0	2050	14	231858
KEOKUK	716	5947	101	19905	0	1691	14793	217564
KOSSUTH	1101	30165	1	24193	0	8616	5746	229675
LEE	615	5584	101	9329	421	1063	3181	101765
LINN	805	10529	1	18398	1444	2628	3672	193636
LOUISA	269	2104	70	11538	0	408	4503	116923
LUCAS	754	4309	0	6573	0	963	4313	61601
LYON	876	19704	0	14826	0	4449	2	149412
MADISON	500	4862	0	11119	0	1170	300	119219
MAHASKA	818	8998	0	20828	754	1991	3892	218866
MARION	1137	7181	0	15052	0	1447	10	163289
M SHALL	605	6899	127	15260	0	1515	3308	153353
MILLS	149	2228	0	8585	0	432	2457	79125
MITCH L	275	16402	773	11630	32	4060	11468	129677

APPENDIX A (CONTINUED)

COUNTY	VARIABLE NAME							
	FD9SH	C10OLD	T11BR	SW12BR	BR13	OC14SL	TUR15R	HOG16S
MONONA	399	4485	9	11819	0	1305	14	107061
MONROE	668	2977	4	5063	0	590	2	54516
MONT RY	229	4885	4	12205	0	1325	7	116241
M TINE	265	3787	281	14246	0	769	2527	158738
O BRIEN	715	17467	155	16286	1586	4200	3501	162024
OSCEOLA	480	11627	0	8598	0	3014	2	90839
PAGE	249	6131	0	12647	0	1103	0	138580
P ALTO	411	10533	154	11510	0	2503	2254	120203
P MOUTH	570	19658	1	32871	584	4650	20026	301078
POC TAS	531	16118	476	12561	0	4322	6188	133341
POLK	383	11311	16	7364	11	3232	80	81953
POT WAT	623	12305	1	23913	16	2554	49	224294
P SHIEK	454	9065	183	15671	10	2031	619	176914
R GOLD	259	3504	0	7310	0	577	1722	77715
SAC	541	14413	0	19385	0	3669	1385	179897
SCOTT	272	11322	1	19173	8	2362	68	209798
SHELBY	208	14026	2	18321	0	4449	1830	171707
SIOUX	906	28691	0	31139	552	6162	1458	290568
STORY	525	12830	279	13199	763	3779	14251	137931
TAMA	517	18286	0	22181	25	3791	17	233638
TAYLOR	516	5430	88	9719	0	1240	847	96599
UNION	245	3998	0	7233	0	808	40	77469
V BUREN	1288	2675	144	20342	250	514	3545	65315
WAPELLO	603	3353	1	5842	103	613	531	73047
WARREN	315	5112	147	11207	0	975	6161	105289
WASH N	591	4947	1295	26643	36	1340	44917	281256
WAYNE	438	4559	350	5741	63	683	15308	64106
WEBSTER	328	8013	70	10190	0	1955	15236	99541
W BAGO	215	14871	0	12012	1459	3883	805	119591
W SHIEK	304	19379	218	19873	16	4626	9583	199250
W DBURY	675	10549	466	20018	0	2274	26417	193064
WORTH	330	11730	271	10244	1796	3573	6986	104059
WRIGHT	675	12784	0	16621	1888	3511	9818	150491

APPENDIX B. ESTIMATED TONS OF FEED TO BE SUPPLIED TO EACH COUNTY, BY EACH LIVESTOCK VARIABLE

COUNTY	VARIABLE NAME							
	M1COWS	MH2HC	B3COWS	FINV4L	FINV5S	OTH6	H7M	ST8SH
ADAIR	812	112	309	1993	237	734	76	26
ADAMS	472	65	216	761	328	438	46	9
ALL KEE	4106	569	203	586	60	613	63	9
APP SE	671	93	230	254	116	377	90	40
AUDUBON	1023	142	126	5105	675	900	44	13
BENTON	1273	176	258	6389	411	1004	68	22
B HAWK	2269	314	86	3712	145	482	82	64
BOONE	463	64	107	3889	203	494	80	20
BREMER	3617	501	40	817	85	316	60	7
BUCH N	2527	350	107	2249	216	493	157	13
B VISTA	612	85	92	4664	232	526	39	44
BUTLER	2612	362	113	1785	380	546	76	10
CALHOUN	472	65	131	2901	614	448	74	21
CARROLL	1124	156	181	6907	466	1010	55	15
CASS	650	90	233	4740	521	842	81	14
CEDAR	1433	198	177	5610	318	771	69	30
C GORDO	876	121	108	2385	197	434	76	23
CH KEE	839	116	98	9402	158	1072	61	20
CH SAW	2441	338	113	1518	118	480	78	8
CLARKE	508	70	230	261	188	377	54	10
CLAY	737	102	107	4831	290	599	57	37
CLAYTON	6011	833	165	1008	81	611	69	12
CLINTON	1876	260	147	10176	188	1223	83	11
C FORD	1606	222	243	5520	512	1123	80	23
DALLAS	493	68	148	2344	296	460	69	16
DAVIS	925	128	184	236	109	325	72	93
DECATUR	687	95	236	234	143	470	75	14
D WARE	4719	654	66	1669	135	475	55	5
DES M S	354	49	127	1442	356	298	58	13
D INSON	703	97	73	2101	243	385	32	32
DUBUQUE	5147	713	153	2696	133	472	54	5
EMMET	534	74	74	2412	320	349	35	14
FAYETTE	5006	693	124	1972	118	650	75	9

APPENDIX B (CONTINUED)

COUNTY	VARIABLE NAME							
	M1COWS	MH2HC	B3COWS	FINV4L	FINV5S	OTH6	H7M	ST8SH
FLOYD	1126	156	97	2752	146	427	56	13
FR KLIN	1346	186	104	4423	446	584	71	64
FREMONT	187	26	114	2644	192	387	40	7
GREENE	404	56	133	3016	438	489	56	20
GRUNDY	1350	187	114	3898	328	564	57	29
GUTHRIE	796	110	250	1577	495	591	74	17
HAM TON	394	55	67	4095	241	443	85	16
H COCK	1204	167	89	3339	97	442	53	21
HARDIN	998	138	117	4564	359	650	73	29
HARR N	718	100	157	2776	320	655	62	6
HENRY	411	57	137	863	447	315	87	21
HOWARD	2553	354	124	734	118	411	45	9
H BOLDT	581	80	51	2750	165	362	35	21
IDA	568	79	109	6181	344	860	41	11
IOWA	1122	155	310	3819	241	862	67	24
JACKSON	2824	391	264	3268	253	785	84	7
JASPER	1495	207	271	3840	651	758	87	23
JEF SON	474	66	134	783	237	303	62	26
JOHNSON	852	118	236	2069	334	614	139	30
JONES	2210	306	156	5560	207	797	90	19
KEOKUK	751	104	216	1234	310	504	103	30
KOSSUTH	1820	252	150	5176	417	785	79	45
LEE	893	124	133	1400	254	330	72	25
LINN	2038	282	180	3134	166	615	103	33
LOUISA	200	28	109	1170	345	278	44	11
LUCAS	446	62	202	198	156	376	109	31
LYON	2133	295	91	6484	149	751	61	36
MADISON	491	68	296	874	311	590	82	21
MAHASKA	1101	153	168	3327	408	536	80	34
MARION	1066	148	176	2134	404	441	61	47
M SHALL	886	123	199	5244	525	759	82	25
MILLS	300	42	81	4148	110	374	40	6
MITCH L	1680	233	62	3891	423	407	50	11

APPENDIX B (CONTINUED)

COUNTY VARIABLE NAME

	M1COWS	MH2HC	B3COWS	FINV4L	FINV5S	OTH6	H7M	ST8SH
MONONA	566	78	108	2297	136	483	58	16
MONROE	439	61	191	172	73	336	104	28
MONT RY	580	80	137	3166	340	604	49	9
M TINE	889	123	123	2286	231	368	54	11
O BRIEN	1288	178	67	5970	245	629	59	29
OSCEOLA	1196	166	51	3326	171	453	19	20
PAGE	543	75	193	3946	315	689	68	10
P ALTO	762	106	84	3207	311	460	45	17
P MOUTH	1192	165	196	10536	356	1194	80	23
POC TAS	604	84	76	4150	229	492	43	22
POLK	607	84	108	1444	253	329	87	16
POT WAT	993	137	185	15326	357	1289	145	26
P SHIEK	1095	152	270	2402	585	702	67	19
R GOLD	710	98	269	599	151	527	65	11
SAC	965	134	163	7595	481	936	50	22
SCOTT	1353	187	100	3414	176	519	83	11
SHELBY	1203	167	149	6656	649	986	68	9
SIOUX	3391	470	65	13010	455	1259	65	37
STORY	650	90	95	3914	172	464	81	22
TAMA	1126	156	284	5010	415	994	62	21
TAYLOR	717	99	269	874	341	542	99	21
UNION	471	65	235	681	186	484	70	10
V BUREN	564	78	181	235	97	293	83	53
WAPELLO	484	67	142	529	131	287	77	25
WARREN	891	123	225	483	445	454	81	13
WASH N	531	74	150	2138	284	426	75	24
WAYNE	906	125	272	452	189	474	87	18
WEBSTER	471	65	121	1757	420	358	93	14
W BAGO	1067	148	56	1254	58	261	34	9
W SHIEK	5342	740	206	1029	113	756	78	13
W DBURY	893	124	169	8917	275	1002	95	28
WORTH	867	120	66	1829	86	268	37	14
WRIGHT	716	99	83	2508	359	425	85	28

APPENDIX B (CONTINUED)

COUNTY	VARIABLE NAME							
	FD9SH	C10OLD	T11BR	SW12BR	BR13	OC14SL	TUR15R	HOG16S
ADAIR	42	3786	0	2133	0	757	44	19991
ADAMS	14	1919	0	1468	0	412	2	13730
ALL KEE	14	2648	0	1846	24	580	1790	18155
APP SE	63	1012	0	804	0	173	3	7409
AUDUBON	21	5686	2	2044	18	1289	133	19278
BENTON	35	5214	0	3786	25	1328	236	36750
B HAWK	103	5029	120	2100	8	1246	3827	22172
BOONE	33	6691	4	1728	12	1515	1414	17381
BREMER	11	6377	65	1650	13	1415	2849	15966
BUCH N	21	5115	23	2390	7	1049	1087	24095
B VISTA	71	4255	157	2664	0	895	4913	25516
BUTLER	16	7396	22	2620	45	1790	1297	23667
CALHOUN	33	3332	113	1755	13	801	1850	16010
CARROLL	24	5822	0	3364	14	1393	1739	29494
CASS	22	3630	0	2159	0	983	107	19753
CEDAR	48	3285	0	4415	0	815	14	44042
C GORDO	37	5953	272	2708	59	1359	4594	22509
CH KEE	31	3034	96	2513	51	804	2643	23718
CH SAW	13	6461	90	1707	53	1165	2121	17754
CLARKE	15	869	0	999	6	150	1969	9585
CLAY	59	3880	0	1821	9	1059	97	17058
CLAYTON	19	4695	32	3481	27	978	283	30892
CLINTON	18	3705	4	3722	0	786	13	38503
C FORD	36	6465	0	3493	0	1704	805	29176
DALLAS	25	3202	7	2001	16	953	816	19648
DAVIS	148	1379	5	885	303	467	1	7943
DECATUR	22	753	0	755	0	71	943	7539
D WARE	9	7417	11	4372	0	1324	2	37952
DES M S	21	1301	0	1456	491	290	32	14345
D INSON	52	3142	64	1041	0	1019	580	8931
DUBUQUE	8	4192	0	3417	813	946	38	30845
EMMET	23	2180	47	975	59	661	598	9116
FAYETTE	14	7072	41	2529	44	1674	909	25464

APPENDIX B (CONTINUED)

COUNTY VARIABLE NAME

COUNTY	FD9SH	C100LD	T11BR	SW12BR	BR13	OC14SL	TUR15R	HOG16S
FLOYD	22	4901	100	1453	143	1347	3838	15400
FR KLIN	103	6722	35	2981	36	1652	2191	25361
FREMONT	11	620	0	778	0	116	215	7404
GREENE	33	2421	4	1783	0	580	1100	16987
GRUNDY	47	4764	51	2411	0	975	1588	24488
GUTHRIE	28	4407	0	1710	6	1112	0	16161
HAM TON	26	2880	221	2174	23	792	23594	21251
H COCK	34	8751	97	2430	25	2364	2567	21246
HARDIN	47	4631	20	2926	0	1151	2806	25952
HARR N	9	1685	1	1593	0	450	2	14524
HENRY	34	1386	256	2006	39	354	8541	19792
HOWARD	15	6133	4	1448	121	1381	561	14070
H BOLDT	34	3467	0	1655	0	1177	344	13455
IDA	18	3609	303	2260	0	733	2852	19920
IOWA	39	2764	106	3151	0	659	3328	29394
JACKSON	12	2230	9	2462	0	381	3	24263
JASPER	36	4357	0	3186	37	1082	273	31833
JEF SON	42	1412	2	1342	0	325	311	14197
JOHNSON	49	2968	117	3538	0	588	8206	34746
JONES	30	3356	0	3448	0	710	4	31929
KEOKUK	47	2061	31	3008	0	586	4528	29961
KOSSUTH	73	10455	0	3656	0	2986	1758	31629
LEE	41	1935	31	1410	311	368	973	14014
LINN	53	3649	0	2781	1068	911	1124	26666
LOUISA	18	729	21	1744	0	141	1378	16102
LUCAS	50	1493	0	993	0	334	1320	8483
LYON	58	6829	0	2241	0	1542	1	20576
MADISON	33	1685	0	1680	0	406	92	16418
MAHASKA	54	3118	0	3148	558	690	1191	30140
MARION	75	2489	0	2275	0	502	3	22487
M SHALL	40	2391	39	2306	0	525	1012	21118
MILLS	10	772	0	1297	0	150	752	10896
MITCH L	18	5685	237	1758	24	1407	3510	17858

APPENDIX B (CONTINUED)

COUNTY	VARIABLE NAME							
	FD9SH	C10OLD	T11BR	SW12BR	BR13	OC14SL	TUR15R	HOG16S
MONONA	26	1554	3	1786	0	452	4	14744
MONROE	44	1032	1	765	0	205	1	7507
MONT RY	15	1693	1	1845	0	459	2	16008
M TINE	17	1312	86	2153	0	267	773	21860
O BRIEN	47	6054	48	2461	1173	1456	1072	22313
OSCEOLA	32	4030	0	1300	0	1045	1	12509
PAGE	16	2125	0	1911	0	382	0	19084
P ALTO	27	3650	47	1740	0	868	690	16553
P MOUTH	38	6813	0	4968	432	1612	6129	41462
POC TAS	35	5586	146	1898	0	1498	1894	18363
POLK	25	3920	5	1113	8	1120	25	11286
POT WAT	41	4265	0	3614	12	885	15	30888
P SHIEK	30	3142	56	2368	7	704	190	24363
R GOLD	17	1214	0	1105	0	200	527	10702
SAC	36	4995	0	2930	0	1272	424	24774
SCOTT	18	3924	0	2898	6	819	21	28891
SHELBY	14	4861	1	2769	0	1542	560	23646
SIOUX	60	9944	0	4706	408	2135	446	40014
STORY	35	4447	85	1995	564	1310	4362	18995
TAMA	34	6337	0	3352	18	1314	5	32175
TAYLOR	34	1882	27	1469	0	430	259	13303
UNION	16	1386	0	1093	0	280	12	10668
V BUREN	85	927	44	3074	185	178	1085	8995
WAPELLO	40	1162	0	883	76	212	162	10059
WARREN	21	1772	45	1694	0	338	1886	14499
WASH N	39	1714	396	4027	27	464	13747	38732
WAYNE	29	1580	107	868	47	237	4685	8828
WEBSTER	22	2777	21	1540	0	677	4663	13708
W BAGO	14	5154	0	1815	1079	1346	247	16469
W SHIEK	20	6716	67	3004	12	1603	2933	27439
W DBURY	45	3656	143	3026	0	788	8085	26587
WORTH	22	4065	83	1548	1328	1238	2138	14330
WRIGHT	45	4431	0	2512	1396	1217	3005	20724

APPENDIX C. MATRIX OF DISTRIBUTION COSTS FOR EACH POTENTIAL PLANT LOCATION TO EACH COUNTY, DOLLARS

COUNTY	POTENTIAL PLANT LOCATION				
	ALGONA	AMES	ATLANTIC	BOONE	BURLINGTON
ADAIR	344883	312401	212590	294719	412334
ADAMS	246419	224776	147002	216991	260198
ALLAMAKEE	377074	408530	528033	413706	410771
APPANOOSE	157020	127082	133878	131957	113653
AUDUBON	416203	361976	231680	344617	552236
BENTON	717034	562925	752546	567071	653478
BLACK HAWK	474202	428776	566583	440980	527769
BOONE	330405	204506	347754	180698	474471
BREMER	365951	366927	471290	380423	439005
BUCHANAN	480090	438924	551318	453112	474260
BUENA VISTA	404753	502914	453498	480929	826794
BUTLER	434406	426904	570395	445849	583453
CALHOUN	243189	270347	288086	238910	460890
CARROLL	531513	439626	411212	400888	798253
CASS	394360	361363	194446	351799	474053
CEDAR	896285	716194	858022	741873	532194
CERRO GORDO	335508	406271	541937	428259	631007
CHEROKEE	450841	530778	501701	513213	873178
CHICKASAW	353785	398192	510055	404375	466756
CLARKE	187080	152237	149746	146687	183587
CLAY	244232	361402	334756	349838	601138
CLAYTON	601713	613903	793382	617839	601713
CLINTON	959721	723408	928386	752686	617159
CRAWFORD	576845	499422	420496	461220	838901
DALLAS	329251	227542	268718	210766	407936
DAVIS	196804	154749	166916	161912	122710
DECATUR	155831	125598	127511	120259	137818
DELAWARE	737687	696156	882879	697889	673854
DES MOINES	341263	271557	289150	281677	113463
DICKINSON	160804	227820	211777	217799	373089
DUBUQUE	679642	597121	784495	660150	536106
EMMET	138794	205716	210735	197591	337878
FAYETTE	538151	542791	701971	562253	568827

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	ALGONA	AMES	ATLANTIC	BOONE	BURLINGTON
FLOYD	301865	343496	442822	355113	461791
FRANKLIN	407094	407094	587582	430217	668734
FREMONT	176900	165877	119026	161042	180270
GREENE	268062	196645	251580	176049	410085
GRUNDY	447156	355135	516340	377562	531843
GUTHRIE	295312	240358	203525	225351	389466
HAMILTON	484258	380215	642590	383034	815825
HANCOCK	276759	409577	549190	415992	520189
HARDIN	453476	324369	532369	348773	605136
HARRISON	290188	260738	184315	257882	368161
HENRY	458916	440001	466848	451427	222268
HOWARD	314056	334570	434815	349639	401868
HUMBOLDT	149849	229464	273974	208956	392207
IDA	405913	407050	375728	396504	699786
IOWA	613487	481830	577011	496001	489069
JACKSON	536618	437024	565789	453368	402247
JASPER	568415	375186	528143	418426	577747
JEFFERSON	296323	234306	251696	244392	161526
JOHNSON	768950	606517	728873	629938	523722
JONES	666529	548469	695495	566234	482373
KEOKUK	598005	472107	505991	495678	432693
KOSSUTH	325973	633283	728355	596367	1019764
LEE	381825	303739	331821	314240	138300
LINN	571305	443774	597058	466056	459850
LOUISA	354951	279709	292171	290546	149462
LUCAS	185566	135292	154806	146364	161870
LYON	445518	568189	533843	550477	930004
MADISON	254104	199162	189958	189958	289396
MAHASKA	591594	431012	493010	457540	474902
MARION	410852	293732	331732	320388	371992
MARSHALL	403840	232699	414011	260863	443037
MILLS	257862	234723	154538	227756	265314
MITCHELL	376118	421303	549096	436537	464916

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	ALGONA	AMES	ATLANTIC	BOONE	BURLINGTON
MONONA	269145	244857	222923	234256	412177
MONROE	149624	116409	124959	122005	120550
MONTGOMERY	325265	293242	174813	286038	335746
MUSCATINE	470110	382859	404244	398439	233547
O BRIEN	404660	538863	497065	515953	892328
OSCEOLA	244642	316554	293276	304098	518497
PAGE	399579	361544	233217	346685	393838
PALO ALTO	177050	318770	328292	306899	530700
PLYMOUTH	829148	952251	887922	915449	1508186
POCAHONTAS	264968	365250	375180	343827	597537
POLK	228494	124575	209075	143949	265450
POTT MIE	750156	685968	392501	663344	887712
POWESHIEK	457789	467890	422868	361097	412163
RINGGOLD	197201	179896	163518	173039	195347
SAC	447319	468616	420525	438413	764743
SCOTT	680095	539482	587563	559374	411102
SHELBY	511037	467474	291977	445789	647664
SIOUX	779900	1013584	962353	972378	1641442
STORY	400502	201290	404851	231051	496723
TAMA	605825	425473	633186	484355	620218
TAYLOR	263064	235747	171929	226686	259456
UNION	180963	158631	136116	161824	200329
VAN BUREN	250237	201214	217142	208370	125946
WAPELLO	201472	162174	171297	167488	133957
WARREN	275682	173296	223723	197361	282215
WASHINGTON	916031	732780	774019	747027	543206
WAYNE	261794	197203	215086	207924	204732
WEBSTER	198844	217512	288518	193517	412736
WINNEBAGO	215994	291885	377686	290853	492743
WINNESHIEK	580746	630178	817091	651822	666036
WOODBURY	623286	629776	597924	610066	1033189
WORTH	242354	299578	385169	311448	443264
WRIGHT	285830	308349	446202	300842	574269

APPENDIX C (CONTINUED)

COUNTY — POTENTIAL PLANT LOCATION

COUNTY	CARROLL	C RAPIDS	C RVILLE	CHARITON	CHAR CTY
ADAIR	277675	403467	342416	290061	416560
ADAMS	194611	271374	202736	178745	287737
ALLAMAKEE	473006	327188	451572	457721	279577
APPANOOSE	147585	133052	56674	82703	137381
AUDUBON	238960	474283	448508	410078	492088
BENTON	659619	372990	644268	653478	577168
BLACK HAWK	493875	367158	486869	496335	333819
BOONE	255551	369290	396850	357907	390315
BREMER	424326	332483	414209	416086	238069
BUCHANAN	502192	299058	490288	497936	376718
BUENA VISTA	377968	637733	667054	607367	523680
BUTLER	503137	453944	493877	496536	275533
CALHOUN	200329	359629	381551	348635	336068
CARROLL	258816	625814	673870	610370	648734
CASS	280526	445998	393703	363393	476289
CEDAR	840914	446657	740138	752247	752247
CERRO GORDO	491795	495734	538856	482897	277234
CHEROKEE	430522	640611	704471	636195	556059
CHICKASAW	455922	362780	446850	448534	204965
CLARKE	170679	189621	129893	95539	200227
CLAY	294856	445060	485984	431908	341469
CLAYTON	702453	481650	684607	686220	489658
CLINTON	831445	567137	790362	794782	793330
CRAWFORD	326323	655176	696438	631003	685443
DALLAS	265679	353210	339456	293118	372973
DAVIS	180315	145276	83153	112156	160040
DECATUR	141062	156720	89622	87823	164366
DELAWARE	790957	467609	774769	778890	619765
DES MOINES	310788	211842	213905	220416	285058
DICKINSON	201951	286469	300715	209639	214941
DUBUQUE	697206	438837	676527	679642	565883
EMMET	175786	254664	276208	244315	192202
FAYETTE	805497	412583	613964	615047	382474

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	CARROLL	C RAPIDS	C RVILLE	CHARITON	CHAR CTY
FLOYD	395504	363070	386535	391063	171055
FRANKLIN	491819	524692	562400	509310	365529
FREMONT	143153	202238	148052	147790	216007
GREENE	180162	315658	335060	305658	330321
GRUNDY	454828	393860	441323	454828	332709
GUTHRIE	202157	336670	321360	288690	352512
HAMILTON	523645	650105	673148	607117	576746
HANCOCK	485441	544778	562975	528656	353864
HARDIN	453476	469507	505916	448857	428628
HARRISON	190067	334536	309313	286473	341325
HENRY	494951	328016	344537	344537	458916
HOWARD	386268	316848	380387	384536	202048
HUMBOLDT	225839	304275	326987	295035	242372
IDA	295318	522738	548482	503120	490427
IOWA	564451	333596	484772	490476	516107
JACKSON	502006	323691	505233	505233	451238
JASPER	515682	484262	447252	370374	517125
JEFFERSON	272373	185136	169399	173331	244392
JOHNSON	903291	335710	620109	623901	643894
JONES	630729	351299	627040	625820	570166
KEOKUK	556152	386566	401757	403930	502392
KOSSUTH	629660	796523	838609	782988	585697
LEE	352763	239080	218485	248441	314984
LINN	521129	226831	510001	513758	475401
LOUISA	329668	211833	244891	249628	297899
LUCAS	167564	168079	103994	71269	175548
LYON	495031	701740	779591	691338	549538
MADISON	231829	280551	238140	187667	296552
MAHASKA	550586	454460	352942	355153	494202
MARION	373374	350866	258263	203446	374720
MARSHALL	362211	308392	365740	333048	347140
MILLS	203858	292605	228852	207147	306013
MITCHELL	484993	439953	376118	483172	245755

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	CARROLL	C RAPIDS	C RVILLE	CHARITON	CHAR CTY
MONONA	190636	304208	327443	299868	312763
MONROE	136161	121141	67366	70100	126651
MONTGOMERY	243382	363340	287149	254848	383677
MUSCATINE	427156	270136	355586	351088	399915
O BRIEN	457709	668637	712758	647714	504080
OSCEOLA	272580	403002	419106	384386	302126
PAGE	313641	454609	319660	316268	472517
PALO ALTO	276825	376665	427528	390614	296171
PLYMOUTH	816575	1166748	1262781	1159480	1012026
POCAHONTAS	280733	467932	485218	450178	385326
POLK	200017	222445	215102	168408	236099
POTT MIE	560856	821132	687002	663344	891460
POWESHIEK	416200	303406	339471	350294	367443
RINGGOLD	181561	205975	143215	139984	237660
SAC	315510	598704	626120	575145	552679
SCOTT	630788	394179	538374	543819	565267
SHELBY	343784	589004	559096	501925	609367
SIOUX	875353	1279341	1384649	1225815	956236
STORY	329631	368339	410070	351957	400502
TAMA	557145	407545	544947	551160	481790
TAYLOR	215024	294092	204132	196304	306727
UNION	165852	205731	155856	117360	214117
VAN BUREN	230744	166998	122722	161422	209573
WAPELLO	187735	150078	106758	108193	175010
WARREN	248772	261889	213413	161837	277010
WASHINGTON	851432	493027	653690	665702	767000
WAYNE	232779	232779	118092	113378	244666
WEBSTER	221504	314931	341018	305761	292332
WINNEBAGO	337694	383907	395497	376267	263773
WINNESHIEK	723203	525610	737974	721561	412748
WOODBURY	521685	810963	849247	770467	747377
WORTH	345333	349929	378657	339008	217162
WRIGHT	392634	451723	512233	433323	342159

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	CHEROKEE	CLARINDA	CLINTON	C BLUFFS	CRESTON
ADAIR	369983	274570	463724	277675	190906
ADAMS	243680	136093	332555	184696	123208
ALLAMAKEE	448497	601161	377976	602289	515180
APPANOOSE	176288	121116	154066	144461	113249
AUDUBON	381992	315475	523622	333686	320930
BENTON	768055	821008	613757	854525	733208
BLACK HAWK	541574	624977	491648	652028	553545
BOONE	386375	396850	441324	402021	339363
BREMER	408465	532987	418864	537324	465471
BUCHANAN	543093	634584	449277	629463	552648
BUENA VISTA	268490	516393	736192	515423	537309
BUTLER	492975	639577	546725	639577	558406
CALHOUN	254629	327811	435086	332711	305920
CARROLL	496455	548279	737456	545030	524409
CASS	384100	256906	536834	263651	251832
CEDAR	1008794	946043	489408	971653	842173
CERRO GORDO	478402	618796	601046	635062	543976
CHEROKEE	234425	529463	805447	492447	570176
CHICKASAW	445988	569928	447691	567746	502168
CLARKE	206201	150511	221421	170679	102415
CLAY	224299	372555	567832	376910	395665
CLAYTON	663207	908606	556318	929924	776055
CLINTON	1119163	1025394	361148	1046407	918537
CRAWFORD	425597	533826	773380	476495	556866
DALLAS	359272	334515	400091	341834	254999
DAVIS	217206	151191	169969	177761	144909
DECATUR	167931	104045	177824	140835	94432
DELAWARE	796123	988569	612212	997823	871368
DES MOINES	392217	289837	221654	325459	251190
DICKINSON	158029	235725	347700	230853	239918
DUBUQUE	766904	902277	458660	916614	771702
EMMET	163213	224424	327151	233219	285140
FAYETTE	599450	783637	545420	793871	686865

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	CHEROKEE	CLARINDA	CLINTON	C BLUFFS	CRESTON
FLOYD	387440	493034	431739	504365	437192
FRANKLIN	502829	641264	626217	656543	582721
FREMONT	146714	85964	234889	98042	125390
GREENE	293167	305658	371617	308487	239225
GRUNDY	498567	567183	486787	586068	508713
GUTHRIE	308481	273091	373245	277891	213078
HAMILTON	621456	716669	618357	726688	630317
HANCOCK	474519	598797	660590	611556	529824
HARDIN	510954	593429	567666	596442	520957
HARRISON	226895	239051	367417	155557	249068
HENRY	627875	466848	392037	518846	405065
HOWARD	382180	486591	377314	507463	424815
HUMBOLDT	210165	311743	375150	311743	265271
IDA	257513	430247	638700	394062	436246
IOWA	669531	623718	493265	637685	556624
JACKSON	599345	633606	282810	633606	548824
JASPER	634679	591439	560258	559269	515682
JEFFERSON	324829	252705	229838	277586	218952
JOHNSON	852655	788731	512831	817280	710882
JONES	744937	782636	412213	785755	690668
KEOKUK	670360	569072	500533	558350	491597
KOSSUTH	612602	788488	944581	756840	695687
LEE	441193	289964	256463	349886	286070
LINN	609780	660050	412647	642002	578915
LOUISA	412225	313547	226874	319425	271103
LUCAS	201198	149634	194016	168586	113948
LYON	374974	597034	879370	510175	610529
MADISON	289396	232636	321425	233442	163513
MAHASKA	650139	545593	548102	544327	467873
MARION	444435	369857	405755	373374	314698
MARSHALL	447682	465144	424438	470044	409875
MILLS	209245	143176	329404	128029	160220
MITCHELL	476631	606784	530757	612704	541769

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	CHEROKEE	CLARINDA	CLINTON	C BLUFFS	CRESTON
MONONA	197318	256945	362755	186184	250708
MONROE	164737	124959	140204	139365	102916
MONTGOMERY	288759	161099	414880	198494	181045
MUSCATINE	520751	442243	273191	444246	402818
O BRIEN	279958	549061	847202	481935	565100
OSCEOLA	190752	329415	487762	283996	334008
PAGE	356602	157049	546467	262526	246412
PALO ALTO	249735	348606	480645	361778	349399
PLYMOUTH	518538	980656	1467459	825013	1015326
POCAHONTAS	259701	425556	543806	425556	402027
POLK	254384	237370	253271	241615	201039
POTT MIE	599286	505719	997180	354752	546345
POWESHIEK	507812	473191	416200	477468	417746
RINGGOLD	219761	118161	257593	175900	109269
SAC	333373	485011	579623	478393	503072
SCOTT	788137	704419	292548	655559	593172
SHELBY	427590	395616	656103	348111	429153
SIOUX	615077	1051859	1492336	894512	1111926
STORY	449606	462156	454929	462156	403774
TAMA	680042	702558	591803	712219	621672
TAYLOR	262046	126211	341961	207683	141447
UNION	201520	134551	242477	161302	86102
VAN BUREN	291468	194427	197200	228086	188402
WAPELLO	227617	172133	175010	191743	156150
WARREN	300666	253276	304456	251388	196213
WASHINGTON	1033637	837465	680752	847313	754395
WAYNE	279813	186009	262413	225219	170909
WEBSTER	266808	331848	381380	325941	286945
WINNEBAGO	322237	423801	463261	421899	375541
WINNESHIEK	688791	937463	634129	932038	799509
WOODBURY	416912	653912	1019580	541605	694170
WORTH	334116	441456	416031	432420	382255
WRIGHT	374589	508197	541107	504873	447311

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	D PORT	DECORAH	D MOINES	DUBUQUE	ES VILLE
ADAIR	434173	482838	263720	476817	363256
ADAMS	292297	335061	204757	339445	244232
ALLAMAKEE	380651	184408	430729	314543	377976
APPANOOSE	138986	161883	116021	160018	179211
AUDUBON	501376	567588	330036	581662	421841
BENTON	617079	584986	605179	583055	789072
BLACK HAWK	497564	402584	437012	400495	529951
BOONE	451950	446325	257256	446325	387170
BREMER	420704	286947	396527	346917	410399
BUCHANAN	451228	344860	466790	332911	522344
BUENA VISTA	764494	594434	532061	620000	380181
BUTLER	562490	420541	472392	475763	498246
CALHOUN	446190	376906	300590	377574	270347
CARROLL	773060	728914	522598	616783	548279
CASS	464602	548728	327784	553050	392312
CEDAR	455806	707521	718506	544404	985360
CERRO GORDO	603780	408356	458799	521593	436485
CHEROKEE	829637	621458	565562	656713	432754
CHICKASAW	450218	234193	420473	374189	399628
CLARKE	198740	227923	116158	228424	210407
CLAY	580044	378618	388558	466120	218150
CLAYTON	555115	383453	653259	412915	655500
CLINTON	373257	740914	776736	464125	1108201
CRAWFORD	811242	793190	555421	798121	555421
DALLAS	383841	421672	195518	426324	366844
DAVIS	154749	177174	145636	178914	219305
DECATUR	164111	188753	107048	190306	175857
DELAWARE	617902	546941	748543	400082	842429
DES MOINES	177289	267568	256336	232805	395198
DICKINSON	357054	226268	241727	284074	110025
DUBUQUE	453698	520970	642393	285296	757282
EMMET	320840	203716	217569	269450	87346
FAYETTE	546271	313025	588830	431118	587619

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	D PORT	DECORAH	D MOINES	DUBUQUE	ES VILLE
FLOYD	435841	277940	378133	372147	355948
FRANKLIN	630178	497427	465816	545116	511805
FREMONT	214004	253756	154409	248234	174501
GREENE	381157	373987	236474	376877	296470
GRUNDY	505377	440120	377562	453761	503130
GUTHRIE	361109	401131	213078	410942	300719
HAMILTON	771773	674808	481440	668169	625934
HANCOCK	650835	461187	434881	569033	398868
HARDIN	574409	509966	397580	566529	522638
HARRISON	351073	393768	244919	385044	285846
HENRY	344537	419020	407092	407092	626621
HOWARD	382773	183828	362774	322698	308096
HUMBOLDT	379045	293665	256810	323240	221017
IDA	618282	557175	441002	545998	392820
IOWA	425504	520660	461571	513779	678586
JACKSON	280947	423722	471594	230777	599345
JASPER	538358	600664	339167	608340	645723
JEFFERSON	208801	237186	222928	242772	332932
JOHNSON	425635	617530	576663	564346	873711
JONES	419507	527368	581693	375653	779517
KEOKUK	440398	521785	427791	517970	680166
KOSSUTH	965427	653666	671746	838609	441329
LEE	231367	303267	287756	264583	441193
LINN	424465	442347	492832	399829	637817
LOUISA	180647	277911	262362	246714	413837
LUCAS	174352	205420	116087	175548	201198
LYON	906177	563079	607849	743850	381159
MADISON	306512	338105	163513	344121	299407
MAHASKA	495394	573114	366306	504486	669116
MARION	379782	434132	224411	383049	450663
MARSHALL	421361	388043	257355	414011	454875
MILLS	312664	363471	218068	357304	249755
MITCHELL	533200	305244	456739	455684	386261

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	D PORT	DECORAH	D MOINES	DUBUQUE	ES VILLE
MONONA	384626	361329	257429	376902	263529
MONROE	129415	147987	92527	147262	167228
MONTGOMERY	390935	452455	274850	430635	304916
MUSCATINE	206123	390836	361305	301854	553199
O BRIEN	823861	591864	568165	696288	359509
OSCEOLA	500935	315365	314163	396815	183470
PAGE	462177	554948	338025	563429	377071
PALO ALTO	490549	350209	342877	406024	187017
PLYMOUTH	1086004	1137550	1010355	1188553	814403
POCAHONTAS	561872	456303	394535	464693	280733
POLK	241615	268900	116414	269853	258197
POTT MIE	863116	1053481	628438	1066087	721229
POWESHIEK	394613	425579	310615	425579	506606
RINGGOLD	238722	266376	163518	266898	221480
SAC	702075	626120	503072	618706	429456
SCOTT	226930	536159	505472	356067	783541
SHELBY	622205	528107	417204	730871	503705
SIOUX	1566889	1045572	1069148	1322628	758278
STORY	463171	461142	268247	457020	457020
TAMA	589580	564328	456196	576355	684744
TAYLOR	299431	350931	218146	352842	259976
UNION	213455	247018	136116	247523	203843
VAN BUREN	179900	203809	188088	208773	295553
WAPELLO	160755	183839	149153	185631	231290
WARREN	289068	314065	142352	318110	302313
WASHINGTON	549457	716649	686129	712248	1035663
WAYNE	246064	213752	176570	281661	281052
WEBSTER	389275	339653	258825	336151	276914
WINNEBAGO	466968	297897	320705	392402	229035
WINNESHIEK	644394	250340	676134	533398	590398
WOODBURY	980698	667401	668867	835369	608780
WORTH	421515	271737	325236	365040	259149
WRIGHT	547276	429120	349687	475642	388934

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	FAIRFIELD	F DODGE	F MADISON	GRINNELL	INDEPEND
ADAIR	365016	317783	422633	341571	417251
ADAMS	242001	222313	265753	236834	287737
ALLAMAKEE	398386	402364	397587	384160	285813
APPANOOSE	97412	145902	114055	107598	138986
AUDUBON	485538	368506	541549	391057	491297
BENTON	557798	661961	655978	461136	401444
BLACK HAWK	462717	424485	527769	371333	260879
BOONE	425470	253847	472217	326996	391830
BREMER	393262	362985	447864	342281	251546
BUCHANAN	416290	433337	469782	401436	199497
BUENA VISTA	701848	375730	841342	582746	582746
BUTLER	520301	409857	590457	375742	360833
CALHOUN	406052	181747	467286	333300	329084
CARROLL	714189	439626	624318	580260	651496
CASS	426606	367339	496302	384100	482979
CEDAR	622323	821290	613752	615928	599399
CERRO GORDO	552874	404186	639116	462158	445592
CHEROKEE	742927	437220	871566	614313	610641
CHICKASAW	422406	391263	476060	365996	292630
CLARKE	153877	174749	180078	159571	199862
CLAY	511467	302543	601138	418449	402462
CLAYTON	586163	601713	586163	575504	390805
CLINTON	685091	831445	677502	652271	650450
CRAWFORD	730049	511381	825922	609294	680851
DALLAS	358117	262623	415339	282455	372973
DAVIS	95680	179193	109522	134701	152629
DECATUR	127878	140126	134647	131765	163857
DELAWARE	676469	673854	661296	639256	382456
DES MOINES	156705	313470	135079	233802	239717
DICKINSON	318846	195351	375093	260494	254482
DUBUQUE	588409	602829	579614	573548	381875
EMMET	290693	178212	339141	237073	235947
FAYETTE	521266	535238	586407	511651	310705

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	FAIRFIELD	F DODGE	F MADISON	GRINNELL	INDEPEND
FLOYD	413070	338648	453372	320532	309839
FRANKLIN	595864	390941	667217	469056	460850
FREMONT	165255	166500	175548	176058	214804
GREENE	358254	199396	406493	282572	323502
GRUNDY	462977	387754	530844	300090	322517
GUTHRIE	343338	252646	382251	285211	349049
HAMILTON	722429	374580	819520	572864	568950
HANCOCK	607310	368865	701897	500490	493335
HARDIN	529751	355416	608867	388688	417538
HARRISON	323916	267426	387235	274727	350329
HENRY	213602	500664	243074	374280	384973
HOWARD	364163	331091	387968	319516	269299
HUMBOLDT	343628	146222	394517	282356	277843
IDA	591592	346364	694314	485691	481818
IOWA	368052	561868	493265	328992	393324
JACKSON	437024	497868	432659	428750	355284
JASPER	502178	517125	586037	283922	515682
JEFFERSON	98581	268310	162512	196217	205034
JOHNSON	471964	697229	531914	480125	488316
JONES	537024	622077	535667	514024	417067
KEOKUK	304141	551684	437354	349688	435808
KOSSUTH	904505	456114	1027206	741297	720024
LEE	177270	347729	117134	261906	263133
LINN	433620	507480	461110	395573	312272
LOUISA	177300	322364	167280	244283	247891
LUCAS	125329	165625	158323	134580	175548
LYON	828736	493840	930004	651930	659858
MADISON	256535	232636	297128	230191	297128
MAHASKA	359624	540502	478976	315013	484242
MARION	303407	367630	374056	246974	374720
MARSHALL	389944	352392	446761	241499	351119
MILLS	243715	235757	283371	249755	306615
MITCHELL	488594	420393	563647	402447	396879

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	FAIRFIELD	F DODGE	F MADISON	GRINNELL	INDEPEND
MONONA	350604	248439	405730	289416	321591
MONROE	80495	134962	114333	89787	130256
MONTGOMERY	304208	297712	351834	310441	382066
MUSCATINE	277756	437219	262516	315720	330010
O BRIEN	784960	465465	889216	611015	591864
OSCEOLA	459662	276701	518497	367108	360771
PAGE	380741	362343	387102	383612	473464
PALO ALTO	453381	248322	532763	371872	367634
PLYMOUTH	1396865	833159	1570634	1093398	1120423
POCAHONTAS	525584	254452	597537	425556	426570
POLK	231513	196953	263430	160259	233409
POTT MIE	788101	685968	874492	718030	872586
POWESHIEK	334068	415416	414614	205993	353909
RINGGOLD	186492	180319	191270	190092	233412
SAC	670180	364671	763325	548972	546459
SCOTT	455765	618296	449331	451923	471180
SHELBY	577608	469975	679879	490410	612228
SIOUX	1461963	875353	1638681	1176666	1136947
STORY	435378	329631	499249	303599	394848
TAMA	535228	544947	621672	346127	433168
TAYLOR	247330	236584	254094	248484	308050
UNION	170054	163364	196657	173916	213786
VAN BUREN	97715	228086	115458	171649	177754
WAPELLO	89577	186340	138252	124657	158142
WARREN	243974	243271	277673	200793	277010
WASHINGTON	439706	834602	546349	593386	627850
WAYNE	181284	230669	198421	196594	245139
WEBSTER	360665	140199	412736	292332	289289
WINNEBAGO	434214	276813	488164	348236	342095
WINNESHIEK	600997	631514	680446	590398	432750
WOODBURY	917678	549082	1074015	745612	725753
WORTH	388378	295247	452238	319082	316418
WRIGHT	507361	267033	577907	412937	402064

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	INDIANOLA	IOWA CTY	I FALLS	KNOXVILLE	LE MARS
ADAIR	234291	389149	360150	273017	401932
ADAMS	190635	270954	250691	212354	261623
ALLAMAKEE	445405	335890	362622	425535	487163
APPANOOSE	105337	129003	132177	90622	191117
AUDUBON	367228	453517	422612	391057	426303
BENTON	635754	463985	569129	598057	828477
BLACK HAWK	484340	427361	317162	461604	576141
BOONE	292978	397513	299777	340594	422685
BREMER	405537	371657	286947	389019	439831
BUCHANAN	481243	368759	376718	462800	589382
BUENA VISTA	562204	665611	487420	592345	344443
BUTLER	487277	493877	307511	466527	528634
CALHOUN	319538	387294	267484	336068	299668
CARROLL	560675	681347	553025	598234	565104
CASS	337894	449925	415613	341482	412776
CEDAR	716194	400810	741873	700855	1132933
CERRO GORDO	480232	534661	310530	459934	515939
CHEROKEE	590917	710203	516091	622921	287914
CHICKASAW	438159	393656	332174	419496	479486
CLARKE	100886	183587	170679	121495	221421
CLAY	402462	488939	347669	424171	270313
CLAYTON	617839	505128	531419	617839	708931
CLINTON	772081	506558	782874	770495	1125740
CRAWFORD	587331	709871	591639	612270	518523
DALLAS	230599	343362	309623	273302	394097
DAVIS	137359	140690	162645	120729	243464
DECATUR	94432	151516	140835	109449	184479
DELAWARE	757536	511689	602401	728138	854037
DES MOINES	240541	181403	280805	226375	424997
DICKINSON	252961	302482	218128	269623	184796
DUBUQUE	665774	478456	541786	641181	828774
EMMET	229151	277324	198416	241423	185067
FAYETTE	604013	473241	476412	575219	634457

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	INDIANOLA	IOWA CTY	I FALLS	KNOXVILLE	LE MARS
FLOYD	383763	383763	265170	368132	419304
FRANKLIN	498790	561063	270799	476953	540742
FREMONT	149545	202238	185296	159691	156922
GREENE	269438	339662	273918	295660	319189
GRUNDY	436466	438917	281727	397946	541558
GUTHRIE	244459	322348	301464	277891	330503
HAMILTON	543307	676435	380215	589771	657055
HANCOCK	474519	576831	360303	503805	500490
HARDIN	426405	509966	251157	428628	553612
HARRISON	262366	314309	300154	279402	232775
HENRY	385880	265598	454805	366888	679312
HOWARD	368250	337034	295648	362072	440243
HUMBOLDT	273974	307444	205331	287352	247422
IDA	465546	541009	427531	491374	325566
IOWA	478863	299141	502626	434687	733684
JACKSON	493607	353422	440396	480160	645296
JASPER	372780	444846	418426	310341	693643
JEFFERSON	209403	172345	246528	185136	364087
JOHNSON	600692	281190	635612	576663	929169
JONES	607893	387830	553242	585978	807533
KEOKUK	382219	349688	496669	328001	730085
KOSSUTH	700001	848357	596367	749167	670330
LEE	269791	211803	314240	258372	463760
LINN	503937	288777	462370	475401	664189
LOUISA	246714	173964	292704	227643	426733
LUCAS	100437	163818	149634	89762	218432
LYON	633303	791506	544773	674337	296779
MADISON	145118	270873	256535	173868	309635
MAHASKA	339553	417623	486801	279294	706722
MARION	203446	341173	329524	161533	479329
MARSHALL	289028	366895	271428	281991	484547
MILLS	210753	276551	261024	223054	231024
MITCHELL	476631	476631	353598	454648	492113

APPENDIX C (CONTINUED)

COUNTY — POTENTIAL PLANT LOCATION

COUNTY	INDIANOLA	IOWA CTY	I FALLS	KNOXVILLE	LE MARS
MONONA	273584	338342	270422	292665	189520
MONROE	91979	115386	122005	70647	179192
MONTGOMERY	266938	343713	330623	278820	308386
MUSCATINE	343214	219834	391617	338512	585190
O BRIEN	590978	729108	517198	632249	307896
OSCEOLA	353611	438587	306692	374983	193170
PAGE	329087	435558	403853	341108	384313
PALO ALTO	354145	426608	305186	376665	293314
PLYMOUTH	1058769	1293525	938299	1115536	402248
POCAHONTAS	413460	503772	336804	441047	319284
POLK	131714	214454	176569	143949	272679
POTT MIE	603164	830699	767092	647668	665994
POWESHIEK	323245	247481	362383	290774	537472
RINGGOLD	152916	218357	201682	167387	231811
SAC	526382	648237	479737	563576	418285
SCOTT	533919	326416	552257	500216	854013
SHELBY	455646	563351	526880	490410	480649
SIOUX	1126964	1379126	995402	1198841	466268
STORY	296143	406963	271974	322196	480693
TAMA	528474	479225	440834	484355	737614
TAYLOR	209753	279682	266062	224537	278426
UNION	125172	199527	182564	143146	215726
VAN BUREN	180322	158207	209968	165372	308976
WAPELLO	136108	141121	166922	116783	241760
WARREN	114842	254501	232681	143488	323418
WASHINGTON	634520	424027	758026	558885	1071385
WAYNE	152996	222878	209941	143566	301811
WEBSTER	277789	342383	212169	303298	302675
WINNEBAGO	334051	406618	275363	357295	349913
WINNESHIEK	684674	568589	561273	672824	747766
WOODBURY	712354	838838	623286	752731	365887
WORTH	338198	374279	243756	324659	365040
WRIGHT	383853	478590	265171	424667	416011

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	MAQUOKETA	M LLTOWN	MASON CTY	MT P ANT	MUSCATINE
ADAIR	462706	353336	405744	387493	387493
ADAMS	316103	244232	279235	242001	272201
ALLAMAKEE	348883	372523	321021	375267	367520
APPANOOSE	151319	113653	147585	107032	131957
AUDUBON	537980	404461	471586	509163	479576
BENTON	509467	435532	642875	596221	581092
BLACK HAWK	448635	344236	408848	486056	480814
BOONE	417023	270855	372207	445510	446325
BREMER	382881	318987	278518	415148	402571
BUCHANAN	398599	376718	423849	442138	431032
BUENA VISTA	690307	537309	508336	743305	726220
BUTLER	503137	348036	328831	552114	541217
CALHOUN	404174	310152	318043	424840	420163
CARROLL	699006	529758	619832	739153	725492
CASS	507332	402027	453759	449925	445209
CEDAR	452744	646505	805814	565796	400810
CERRO GORDO	552874	404186	229363	585939	577667
CHEROKEE	728735	572458	519787	815124	768257
CHICKASAW	406883	352617	268570	429967	435460
CLARKE	210407	156002	190454	165223	186221
CLAY	510494	390164	315678	560060	531793
CLAYTON	489658	564270	522564	557493	538443
CLINTON	364150	700371	833942	646774	482306
CRAWFORD	726705	566559	657755	780012	765105
DALLAS	402994	268718	353210	382211	384656
DAVIS	167261	145276	173205	108861	142664
DECATUR	177041	138086	157597	136708	154934
DELAWARE	497007	623461	682715	653774	576305
DES MOINES	217229	251190	303396	128902	148465
DICKINSON	310696	245653	199288	348368	341687
DUBUQUE	352155	544543	597121	568144	471039
EMMET	289586	221745	178212	315160	301159
FAYETTE	494277	494277	466797	547095	530108

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	MAQUOKETA	M LLTOWN	MASON CTY	MT P ANT	MUSCATINE
FLOYD	397245	409039	206151	425291	423816
FRANKLIN	581486	397860	305445	625214	616930
FREMONT	239951	177325	207937	172065	200602
GREENE	354172	266686	317462	377442	364798
GRUNDY	455895	269493	371433	489193	482452
GUTHRIE	380443	289555	333618	364268	343338
HAMILTON	716669	484258	526432	757276	753489
HANCOCK	600227	463715	274612	645278	632686
HARDIN	525033	319923	355416	566529	559565
HARRISON	382853	286473	326952	345833	332268
HENRY	380264	403676	492655	173727	282949
HOWARD	347346	311872	234278	368920	363461
HUMBOLDT	328545	262558	225839	363411	358684
IDA	600117	446749	470746	627923	624323
IOWA	468018	402508	516107	420899	407112
JACKSON	204749	421984	487462	423722	336685
JASPER	558280	324754	497445	534614	529479
JEFFERSON	226979	215206	263119	121205	179234
JOHNSON	466503	549389	697229	425635	406551
JONES	312326	491162	610523	514024	373213
KEOKUK	487298	421270	541299	358358	380045
KOSSUTH	871705	691110	485686	954066	942705
LEE	254454	282623	344133	148318	201771
LINN	327206	391292	508740	416927	376334
LOUISA	217400	259782	319425	152798	140547
LUCAS	191545	144408	176719	140274	163818
LYON	822780	615914	512421	873414	865967
MADISON	319147	221000	283777	270873	271705
MAHASKA	531385	375247	526368	413177	451355
MARION	401411	266324	360523	341173	340168
MARSHALL	380027	190463	353646	409875	402232
MILLS	350453	256228	293216	254120	293828
MITCHELL	488594	373439	258775	517220	510969

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	MAQUOKETA	M LLTOWN	MASON CTY	MT P ANT	MUSCATINE
MONONA	342681	265239	304679	370553	363461
MONROE	137928	105102	135864	93069	120246
MONTGOMERY	419627	319657	361703	320921	364160
MUSCATINE	256423	353703	421487	248804	152766
O BRIEN	786516	578052	475161	828529	820749
OSCEOLA	450003	335494	281024	482494	476347
PAGE	501370	391848	448917	400199	433634
PALO ALTO	443272	346162	258289	477947	467981
PLYMOUTH	1369714	1037382	950288	1472890	1451168
POCAHONTAS	502601	403587	364098	557366	553991
POLK	254384	142928	222445	246393	240525
POTT MIE	943787	741300	842172	830699	811500
POWESHIEK	405195	267320	412987	372363	359792
RINGGOLD	256036	195815	224332	195347	221138
SAC	537478	508496	528000	715012	706403
SCOTT	284086	490270	604367	431230	305251
SHELBY	677091	503705	581503	603645	589918
SIOUX	1392933	1066599	897400	1536516	1492336
STORY	430822	242213	372398	464186	454929
TAMA	523258	330765	533575	572479	565724
TAYLOR	326419	257341	287396	261017	279682
UNION	230272	179258	205731	179258	202303
VAN BUREN	192065	186750	225410	113851	162571
WAPELLO	172962	145774	180110	106042	145281
WARREN	303385	197361	267337	255101	258035
WASHINGTON	655716	669543	827269	433421	449099
WAYNE	260786	200206	245601	199608	217228
WEBSTER	357104	262831	273338	378739	367417
WINNEBAGO	421899	327378	214544	453009	449270
WINNESHIEK	576517	579716	475229	603890	622111
WOODBURY	838838	691448	706014	927848	899015
WORTH	381071	296119	168180	416031	407774
WRIGHT	502322	373210	302725	527454	519237

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	NEWTON	PELLA	PERRY	OELWEIN	OSKALOOSA
ADAIR	318835	310193	246676	430068	312401
ADAMS	227989	222313	199269	300710	222810
ALLAMAKEE	403146	414435	440247	235892	404691
APPANOOSE	105897	90622	130779	144750	89494
AUDUBON	371041	401521	291788	509163	419488
BENTON	520830	564982	626702	435532	549252
BLACK HAWK	415645	435666	479908	285888	427361
BOONE	303187	346580	209620	396149	369290
BREMER	362985	379578	402571	222883	372576
BUCHANAN	427485	444222	478937	231354	441074
BUENA VISTA	561010	599508	484859	546287	624427
BUTLER	416268	431438	482220	333104	443071
CALHOUN	321702	341190	244621	344532	361904
CARROLL	554578	596019	408653	681347	640337
CASS	366362	352888	312601	491867	369255
CEDAR	626540	676741	721874	632696	648443
CERRO GORDO	446843	475575	471659	421077	520481
CHEROKEE	595035	618506	516091	574716	656713
CHICKASAW	389636	395971	429967	265125	396718
CLARKE	146687	134474	139820	205529	142114
CLAY	405382	425811	352639	397953	451106
CLAYTON	600347	598953	665366	356450	613903
CLINTON	682089	706679	770495	680571	707859
CRAWFORD	586226	629585	461220	713243	656479
DALLAS	236694	253470	178742	382211	293118
DAVIS	133329	118093	160040	158522	102931
DECATUR	125985	119383	119825	166098	120688
DELAWARE	680263	699622	759008	426504	691937
DES MOINES	242135	228060	276771	248828	213905
DICKINSON	252570	270835	223113	251789	284074
DUBUQUE	601395	619316	670158	411597	605641
EMMET	229569	241073	203017	226171	258092
FAYETTE	539104	552844	593600	275981	543667

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	NEWTON	PELLA	PERRY	OELWEIN	OSKALOOSA
FLOYD	352573	345380	375842	284316	354279
FRANKLIN	448685	491819	484540	432506	528988
FREMONT	169786	164625	151826	230748	163018
GREENE	273918	298076	176049	339662	316866
GRUNDY	344944	379605	428862	351050	397946
GUTHRIE	247178	263552	183064	363023	306445
HAMILTON	534886	598632	467381	598632	641275
HANCOCK	486466	516492	449238	475663	537981
HARDIN	357640	435297	415315	442534	462418
HARRISON	265478	285846	237514	354057	297887
HENRY	387694	355558	444478	400028	322824
HOWARD	334570	338657	368250	242686	344241
HUMBOLDT	275667	287352	218599	263243	306814
IDA	465546	497794	397725	509961	519644
IOWA	356567	379537	506463	434687	372657
JACKSON	449106	462657	496173	379801	449106
JASPER	240682	310341	408800	534614	348767
JEFFERSON	205669	182190	243856	215206	157595
JOHNSON	501938	543533	616195	543533	526453
JONES	553242	566234	617005	456040	559968
KEOKUK	380045	319331	493649	464427	271586
KOSSUTH	718311	768762	598441	701055	799125
LEE	270424	254963	309082	274824	234963
LINN	439494	453358	500727	352840	446556
LOUISA	251847	232851	294812	276696	217400
LUCAS	120356	108262	145881	182366	113236
LYON	642628	679584	553273	610529	710813
MADISON	210657	198010	166969	303836	203758
MAHASKA	323930	261459	463527	505579	223529
MARION	209907	182498	317929	380949	201830
MARSHALL	225663	269664	301355	366895	306647
MILLS	238307	228852	215918	312664	237802
MITCHELL	423933	426499	460859	374814	432874

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	NEWTON	PELLA	PERRY	OELWEIN	OSKALOOSA
MONONA	278481	297859	238409	322322	309811
MONROE	89245	73930	121141	130901	70647
MONTGOMERY	295061	287149	268437	398959	295061
MUSCATINE	336052	309492	364004	347626	308422
O BRIEN	596795	637876	520933	587388	671414
OSCEOLA	353611	375767	309853	334509	394491
PAGE	367139	352377	330555	485614	350665
PALO ALTO	361778	382568	312660	346987	396581
PLYMOUTH	1041392	1139973	925976	1024975	1200584
POCAHONTAS	414708	444754	343827	403587	464693
POLK	137831	154141	142928	240151	172494
POTT MIE	684934	661987	621522	919611	682768
POWESHIEK	233063	256496	362383	367443	245693
RINGGOLD	182767	176818	161799	241359	180742
SAC	524691	564770	445702	543922	593580
SCOTT	473395	488455	536159	489375	472287
SHELBY	469975	501925	389149	619344	519428
SIOUX	1129428	1216044	985972	1121952	1279341
STORY	275681	305442	281273	411085	338930
TAMA	397314	435704	512484	468992	435704
TAYLOR	238971	234005	212434	316613	236165
UNION	164869	155856	134551	218946	158083
VAN BUREN	176865	164259	205497	184254	146912
WAPELLO	133248	113915	167201	164492	96024
WARREN	177877	162973	192781	286618	173296
WASHINGTON	632319	562028	735259	667622	477349
WAYNE	175635	160535	205278	253991	169030
WEBSTER	282048	303921	202850	303921	317453
WINNEBAGO	343126	368191	322237	335293	381876
WINNESHIEK	626173	638023	683617	390270	640582
WOODBURY	718545	742741	618680	619846	782849
WORTH	319082	335768	326934	301259	346096
WRIGHT	390188	422806	360936	374589	447311

APPENDIX C (CONTINUED)

COUNTY — POTENTIAL PLANT LOCATION

COUNTY	OTTUMWA	RED OAK	S DOAH	SIOUX CTY	SPENCER
ADAIR	344883	259080	300912	395669	383249
ADAMS	218647	127172	154940	258266	249102
ALLAMAKEE	419421	585354	615838	507207	397587
APPANOOSE	84398	129003	127365	186449	179936
AUDUBON	454511	306369	355547	417867	402514
BENTON	557798	782551	858229	850823	777835
BLACK HAWK	435666	612728	657410	559252	540530
BOONE	398868	387170	411208	417989	394027
BREMER	375261	514442	549205	483547	433956
BUCHANAN	440010	608868	657506	555286	543093
BUENA VISTA	675809	492419	514454	438278	295300
BUTLER	493877	613034	660374	580747	495657
CALHOUN	384781	321702	338152	285015	266067
CARROLL	680110	526193	569417	549862	509397
CASS	398833	240014	283908	400035	377448
CEDAR	668340	888258	993183	1041682	1028180
CERRO GORDO	539875	590063	632351	524929	423973
CHEROKEE	715909	516091	537303	356985	352544
CHICKASAW	398920	554557	585164	484041	398920
CLARKE	135239	139820	157047	217903	191686
CLAY	495822	356585	370795	318752	162930
CLAYTON	619151	849409	942360	804369	673702
CLINTON	714808	969436	1110393	1152050	1042596
CRAWFORD	688815	479046	499422	435771	509567
DALLAS	345620	325584	347777	388663	365961
DAVIS	79858	163005	156194	238695	220978
DECATUR	120259	119825	116059	180968	134026
DELAWARE	704821	979249	1063780	879053	819145
DES MOINES	186549	276771	281241	409352	395943
DICKINSON	304240	224707	234286	205465	108175
DUBUQUE	619316	831917	938119	778098	731448
EMMET	272830	227889	237821	205395	119609
FAYETTE	546271	773377	838547	717000	607390

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	OTTUMWA	RED OAK	S DOAH	SIOUX CTY	SPENCER
FLOYD	389270	486817	515626	435841	349945
FRANKLIN	562400	634062	677839	593523	517850
FREMONT	166189	92322	73879	155500	164625
GREENE	336604	294834	316269	318043	301209
GRUNDY	437691	519541	594103	522673	514184
GUTHRIE	320327	262185	291226	324930	314769
HAMILTON	687738	701734	741779	646410	622960
HANCOCK	571012	592261	631279	544778	383867
HARDIN	503840	580954	608867	569938	520957
HARRISON	308276	206182	221131	230328	265478
HENRY	256932	447991	456464	654221	635403
HOWARD	341075	474236	517603	438434	341870
HUMBOLDT	328021	297734	314724	272806	216196
IDA	554691	402461	404777	308558	342575
IOWA	388746	626660	648326	745476	681579
JACKSON	458582	633606	682392	604105	613601
JASPER	447252	573522	617030	674603	642460
JEFFERSON	123165	242772	262670	367647	331071
JOHNSON	543533	752324	829719	885906	866701
JONES	566234	782636	812171	826057	763841
KEOKUK	295471	552819	569072	708011	675963
KOSSUTH	796523	789838	826853	704546	470900
LEE	207351	317190	300850	466983	439582
LINN	458566	636438	662810	682071	623835
LOUISA	201802	298903	330399	433181	414644
LUCAS	107549	146364	159431	212880	203543
LYON	713379	563079	558703	346174	362625
MADISON	235824	223304	244771	304911	288782
MAHASKA	279294	530069	551803	686529	661839
MARION	263111	364561	385903	481429	450663
MARSHALL	358585	454875	481626	474023	455756
MILLS	230486	113820	122348	221230	237802
MITCHELL	482240	599643	632740	541769	424801

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	OTTUMWA	RED OAK	S DOAH	SIOUX CTY	SPENCER
MONONA	327443	237045	244249	161683	245476
MONROE	66817	122005	129933	175692	167228
MONTGOMERY	289286	128674	162348	304208	292770
MUSCATINE	309492	447249	464169	598427	431195
O BRIEN	718216	528258	519688	365949	282088
OSCEOLA	420619	315365	307327	225944	177404
PAGE	358266	181954	167292	378556	359913
PALO ALTO	431258	354145	347797	325721	185604
PLYMOUTH	1267501	921798	954214	450995	728646
POCAHONTAS	485218	405109	426570	366382	271972
POLK	217008	231513	246393	193900	256574
POTT MIE	745761	412798	438945	653583	682768
POWESHIEK	288968	462448	480822	546870	506606
RINGGOLD	174488	144025	141595	230218	223468
SAC	626120	455181	505287	409354	353500
SCOTT	480749	665129	692281	809585	736473
SHELBY	546932	339481	363233	468724	454275
SIOUX	1412261	997272	993533	561679	634150
STORY	412079	449606	307305	470172	451739
TAMA	497151	691613	720712	713929	680042
TAYLOR	233100	154658	143483	274952	266549
UNION	156978	120483	148618	213125	205731
VAN BUREN	117882	211925	202947	227018	292635
WAPELLO	71687	167201	181249	243115	228995
WARREN	217995	246755	259732	318110	303921
WASHINGTON	511849	847313	864597	1087169	1039644
WAYNE	162425	205813	199608	298787	284737
WEBSTER	343051	314931	336863	287731	272418
WINNEBAGO	402782	404700	428541	381876	273912
WINNESHIEK	641862	915765	968203	783430	613849
WOODBURY	863035	616287	635728	338999	549082
WORTH	365040	422419	448654	382847	299578
WRIGHT	484340	489003	514616	450636	382556

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	S LAKE	WASH TON	WATERLOO	WAVERLY	WEB CTY
ADAIR	350387	359512	403467	409436	332670
ADAMS	227547	253275	277258	281852	231357
ALLAMAKEE	430085	358610	317808	306101	383292
APPANOOSE	134079	116405	132404	137708	138986
AUDUBON	342792	475175	465117	477832	388846
BENTON	761725	517981	412807	481045	623568
BLACK HAWK	487704	451094	208795	248397	379662
BOONE	353493	412193	366298	375977	240247
BREMER	395251	391872	204339	187483	346917
BUCHANAN	520415	402833	249266	301054	409705
BUENA VISTA	239468	704732	547530	512463	445564
BUTLER	472392	509190	307511	249941	382153
CALHOUN	213184	399433	310979	321702	217480
CARROLL	418977	705648	610370	631710	488719
CASS	358262	412776	456747	465297	387219
CEDAR	955906	513862	652184	696637	781666
CERRO GORDO	471659	549954	408356	354230	364633
CHEROKEE	281216	749998	580249	537303	477089
CHICKASAW	427153	403073	247936	232470	374189
CLARKE	195290	170679	192094	195681	158577
CLAY	204350	509520	396433	369019	323706
CLAYTON	641616	555115	449729	422726	574547
CLINTON	961644	612943	699056	728738	832694
CRAWFORD	402698	748470	648686	670195	538672
DALLAS	340254	354483	353210	360375	261094
DAVIS	205369	120068	146340	151778	179193
DECATUR	161503	140126	156720	161771	132427
DELAWARE	770551	602401	455870	538112	655311
DES MOINES	356862	160819	253505	267568	297310
DICKINSON	143258	315937	242611	234286	207367
DUBUQUE	673357	533183	441318	497535	579614
EMMET	155367	285703	222200	206648	189251
FAYETTE	575219	491441	361644	333855	529051

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	S LAKE	WASH TON	WATERLOO	WAVERLY	WEB CTY
FLOYD	371489	397245	268367	230075	319395
FRANKLIN	500154	586373	390941	333172	351665
FREMONT	151075	182791	207937	209557	172886
GREENE	265310	354172	317462	322462	228233
GRUNDY	475529	462000	271535	296004	340858
GUTHRIE	284330	337415	338174	345510	269020
HAMILTON	551761	715197	532067	523645	301471
HANCOCK	449238	598797	455988	415992	336740
HARDIN	481561	525033	355416	379820	306609
HARRISON	222284	334536	326952	328476	276084
HENRY	571363	230934	405065	426895	475785
HOWARD	369591	347346	232874	221673	322074
HUMBOLDT	198091	466599	259738	236704	175179
IDA	257513	575678	454769	446076	383832
IOWA	630523	347383	400232	468018	533065
JACKSON	571810	401151	383587	414557	477346
JASPER	601948	487630	479100	494236	484262
JEFFERSON	307800	135956	218437	228644	258059
JOHNSON	804840	373846	555093	591469	678480
JONES	706724	480421	477980	521564	591593
KEOKUK	627879	291123	437354	468315	525553
KOSSUTH	583326	889092	689957	650407	521186
LEE	416209	186185	280863	295295	331821
LINN	582577	354980	374194	424465	487053
LOUISA	376241	152798	261519	276089	305191
LUCAS	191545	146364	169845	173147	156802
LYON	422079	807887	618594	564798	524472
MADISON	265816	252836	282497	289396	230191
MAHASKA	616831	361859	457540	462036	516681
MARION	422932	303407	349932	389654	345158
MARSHALL	421361	385103	310156	327775	317212
MILLS	215918	266569	290148	299330	245612
MITCHELL	457774	489484	346167	312696	401351

APPENDIX C (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	S LAKE	WASH TON	WATERLOO	WAVERLY	WEB CTY
MONONA	195086	335452	304208	316445	252891
MONROE	154319	101277	121433	125945	129933
MONTGOMERY	269909	335746	366617	372322	305610
MUSCATINE	494633	224417	353057	370199	414495
O BRIEN	335857	739953	565100	551264	494240
OSCEOLA	216231	457906	335981	326754	289021
PAGE	333377	396431	449863	457447	378556
PALO ALTO	235483	447874	343702	323722	279682
PLYMOUTH	627351	1300584	1048828	973262	872090
POCAHONTAS	235176	514132	403587	376234	289493
POLK	238596	231026	221275	226905	170451
POTT MIE	616189	764345	851707	859302	714830
POWESHIEK	479999	321438	312421	343085	394613
RINGGOLD	206389	202987	222811	211644	188193
SAC	275281	651172	518447	537478	413832
SCOTT	719149	396276	494607	528239	585300
SHELBY	404247	589004	578594	593524	492430
SIOUX	714268	1464724	1059038	1040729	920000
STORY	424195	430822	368339	381511	288707
TAMA	644301	525025	371721	405009	502281
TAYLOR	242613	259456	292090	300098	247330
UNION	187036	184356	204983	209706	171811
VAN BUREN	265760	127562	187756	196285	219942
WAPELLO	213703	111771	149153	157353	186692
WARREN	285992	233473	265436	269558	228610
WASHINGTON	973263	326778	671463	712248	810439
WAYNE	263663	207399	232254	241821	218047
WEBSTER	232174	379629	267758	276914	164194
WINNEBAGO	320705	419047	328087	307295	244961
WINNESHIEK	668317	576517	482713	450248	599550
WOODBURY	449155	895606	694170	570198	581533
WORTH	329100	382847	295247	268933	281116
WRIGHT	364699	498871	360936	319619	233243

APPENDIX D. IOWA ROAD MILEAGE MATRIX FOR EACH POTENTIAL PLANT LOCATION TO EACH COUNTY, MILES

COUNTY	POTENTIAL PLANT LOCATION				
	ALGONA	AMES	ATLANTIC	BOONE	BURLINGTON
ADAIR	137	103	37	90	225
ADAMS	190	145	48	130	217
ALLAMAKEE	178	216	345	223	219
APPANOOSE	251	141	169	160	102
AUDUBON	149	99	27	89	290
BENTON	197	98	222	100	152
BLACK HAWK	147	109	238	118	199
BOONE	94	20	107	6	253
BREMER	127	128	254	143	213
BUCHANAN	177	133	250	147	172
BUENA VISTA	81	142	105	124	373
BUTLER	106	101	228	114	242
CALHOUN	70	89	103	67	320
CARROLL	109	70	59	55	299
CASS	161	122	15	113	256
CEDAR	275	163	256	180	74
CERRO GORDO	61	95	213	109	290
CHEROKEE	104	172	142	153	403
CHICKASAW	109	156	280	165	237
CLARKE	184	100	96	92	176
CLAY	59	166	129	148	403
CLAYTON	184	193	321	196	184
CLINTON	311	173	295	190	106
CRAWFORD	145	96	65	81	331
DALLAS	125	49	76	38	228
DAVIS	283	164	199	185	86
DECATUR	211	114	119	101	151
DELAWARE	195	170	286	171	151
DES MOINES	334	220	256	242	10
DICKINSON	74	187	151	167	420
DUBUQUE	244	177	311	226	126
EMMET	59	167	178	145	397
FAYETTE	158	163	290	180	185

APPENDIX D (CONTINUEC)

COUNTY	POTENTIAL PLANT LOCATION				
	ALGONA	AMES	ATLANTIC	BOONE	BURLINGTON
FLOYD	89	124	251	137	269
FRANKLIN	76	76	201	86	269
FREMONT	252	214	87	199	260
GREENE	95	43	83	28	283
GRUNDY	131	74	199	85	214
GUTHRIE	126	76	49	65	263
HAMILTON	72	35	149	36	270
HANCOCK	29	91	205	94	180
HARDIN	107	46	175	57	240
HARRISON	197	145	60	140	316
HENRY	222	200	232	213	28
HOWARD	140	173	301	192	265
HUMBOLDT	24	90	146	73	324
IDA	123	124	99	115	373
IOWA	227	115	195	125	120
JACKSON	268	165	292	182	126
JASPER	169	56	132	74	176
JEFFERSON	287	172	204	190	64
JOHNSON	258	137	228	155	92
JONES	242	142	263	158	98
KEOKUK	247	128	160	149	100
KOSSUTH	10	122	186	103	355
LEE	352	240	282	258	24
LINN	228	112	254	129	124
LOUISA	314	195	217	214	34
LUCAS	214	90	128	109	147
LYON	126	248	211	228	486
MADISON	134	73	65	65	196
MAHASKA	223	93	134	108	120
MARION	202	82	109	99	154
MARSHALL	151	32	165	48	196
MILLS	239	189	63	176	255
MITCHELL	104	145	278	164	193

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	ALGONA	AMES	ATLANTIC	BOONE	BURLINGTON
MONONA	178	132	101	116	373
MONROE	242	120	149	138	133
MONTGOMERY	214	165	40	151	232
MUSCATINE	298	195	223	215	53
O BRIEN	88	194	155	175	435
OSCEOLA	103	214	178	194	452
PAGE	240	187	59	169	231
PALO ALTO	24	139	153	124	376
PLYMOUTH	134	200	169	182	417
POCAHONTAS	51	113	122	96	349
POLK	140	22	108	41	213
POTT MIE	209	168	35	149	294
POWESHIEK	200	211	163	101	149
RINGGOLD	182	137	104	122	178
SAC	101	115	88	96	351
SCOTT	318	202	251	221	94
SHELBY	169	126	35	110	285
SIOUX	107	224	197	202	456
STORY	124	8	128	24	227
TAMA	169	66	188	89	179
TAYLOR	210	157	69	138	203
UNION	156	105	74	111	205
VAN BUREN	301	192	232	209	56
WAPELLO	257	145	174	162	87
WARREN	176	51	95	72	186
WASHINGTON	273	161	187	172	73
WAYNE	251	114	148	133	127
WEBSTER	49	63	126	45	300
WINNEBAGO	49	103	214	102	348
WINNESHIEK	158	197	327	214	226
WOODBURY	157	163	137	146	393
WORTH	73	122	246	137	311
WRIGHT	52	64	171	60	294

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	CARROLL	C RAPIDS	C RVILLE	CHARITON	CHAR CTY
ADAIR	79	213	134	87	231
ADAMS	96	242	107	80	270
ALLAMAKEE	290	115	269	275	79
APPANOOSE	214	165	0	46	180
AUDUBON	31	213	186	142	234
BENTON	157	31	145	152	105
BLACK HAWK	170	76	161	172	60
BOONE	50	127	160	116	151
BREMER	196	97	185	187	41
BUCHANAN	197	50	186	193	89
BUENA VISTA	69	263	283	238	163
BUTLER	167	120	156	159	29
CALHOUN	40	196	227	182	165
CARROLL	0	179	214	168	195
CASS	66	221	160	124	258
CEDAR	246	46	179	186	186
CERRO GORDO	168	172	210	157	33
CHEROKEE	93	266	310	263	192
CHICKASAW	223	117	212	214	19
CLARKE	139	190	70	25	217
CLAY	92	270	311	257	137
CLAYTON	264	96	253	254	100
CLINTON	244	87	214	217	216
CRAWFORD	28	207	242	189	232
DALLAS	74	156	137	92	183
DAVIS	242	133	26	70	180
DECATUR	164	214	49	46	242
DELAWARE	232	59	220	223	117
DES MOINES	288	109	112	122	250
DICKINSON	130	301	325	146	159
DUBUQUE	257	77	241	244	149
EMMET	103	273	311	255	133
FAYETTE	360	78	223	224	65

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	CARROLL	C RAPIDS	C RVILLE	CHARITON	CHAR CTY
FLOYD	189	147	179	184	7
FRANKLIN	120	146	181	133	58
FREMONT	142	313	159	158	347
GREENE	31	152	182	137	176
GRUNDY	138	93	126	138	63
GUTHRIE	48	187	166	118	209
HAMILTON	86	155	174	125	108
HANCOCK	145	201	218	187	65
HARDIN	107	118	148	104	93
HARRISON	65	271	231	191	280
HENRY	263	89	99	99	222
HOWARD	247	144	237	244	44
HUMBOLDT	87	197	236	183	102
IDA	56	249	270	225	211
IOWA	185	45	117	121	141
JACKSON	234	74	238	238	180
JASPER	123	103	86	54	124
JEFFERSON	250	88	72	76	190
JOHNSON	334	23	147	150	168
JONES	210	44	207	206	162
KEOKUK	205	78	85	86	156
KOSSUTH	120	232	260	222	98
LEE	311	123	96	138	259
LINN	182	6	173	176	137
LOUISA	279	90	132	140	228
LUCAS	166	168	46	0	187
LYON	176	349	385	341	227
MADISON	103	182	111	63	208
MAHASKA	187	106	58	59	135
MARION	156	128	60	26	158
MARSHALL	109	75	112	89	97
MILLS	124	299	178	130	321
MITCHELL	214	169	104	212	32

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	CARROLL	C RAPIDS	C RVILLE	CHARITON	CHAR CTY
MONONA	71	241	276	232	256
MONROE	191	135	23	28	156
MONTGOMERY	95	272	153	107	297
MUSCATINE	255	77	160	153	217
O BRIEN	120	302	334	287	163
OSCEOLA	141	335	356	311	191
PAGE	122	301	129	125	320
PALO ALTO	94	221	285	243	112
PLYMOUTH	128	302	342	299	233
POCAHONTAS	60	227	250	206	132
POLK	96	129	117	65	156
POTT MIE	93	259	169	149	296
POWESHIEK	154	68	88	94	106
RINGGOLD	141	202	77	73	276
SAC	41	229	255	207	188
SCOTT	282	86	201	206	227
SHELBY	59	240	210	158	258
SIOUX	151	340	363	318	194
STORY	77	98	133	89	124
TAMA	128	59	120	124	88
TAYLOR	118	269	102	93	288
UNION	119	219	100	50	243
VAN BUREN	264	111	52	101	212
WAPELLO	217	115	49	51	183
WARREN	127	149	86	41	178
WASHINGTON	237	57	113	119	183
WAYNE	187	187	25	20	211
WEBSTER	66	168	204	151	131
WINNEBAGO	160	223	241	212	82
WINNESHIEK	269	116	278	268	65
WOODBURY	94	288	310	265	252
WORTH	187	193	235	179	55
WRIGHT	114	176	240	154	82

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	CHEROKEE	CLARINDA	CLINTON	C BLUFFS	CRESTON
ADAIR	173	77	284	79	23
ADAMS	185	37	340	86	24
ALLAMAKEE	266	394	179	395	332
APPANOOSE	303	122	239	203	101
AUDUBON	115	73	266	83	76
BENTON	234	268	125	286	208
BLACK HAWK	212	285	167	305	224
BOONE	146	160	211	168	100
BREMER	179	310	190	314	248
BUCHANAN	240	314	143	310	251
BUENA VISTA	20	155	331	154	176
BUTLER	155	285	205	285	216
CALHOUN	78	151	292	159	122
CARROLL	92	119	263	117	105
CASS	147	52	313	56	49
CEDAR	332	300	60	313	247
CERRO GORDO	152	281	268	293	215
CHEROKEE	5	171	361	134	204
CHICKASAW	211	334	213	332	273
CLARKE	234	97	270	139	34
CLAY	46	180	373	185	208
CLAYTON	234	373	145	385	310
CLINTON	372	345	19	356	290
CRAWFORD	67	115	291	87	130
DALLAS	166	131	217	140	67
DAVIS	331	151	208	233	132
DECATUR	254	73	279	163	57
DELAWARE	236	342	113	347	280
DES MOINES	388	257	124	310	182
DICKINSON	71	203	382	193	212
DUBUQUE	300	365	85	373	303
EMMET	87	207	380	228	327
FAYETTE	210	345	166	352	280

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	CHEROKEE	CLARINDA	CLINTON	C BLUFFS	CRESTON
FLOYD	180	299	235	310	243
FRANKLIN	128	251	236	261	197
FREMONT	154	35	372	54	97
GREENE	121	137	235	141	74
GRUNDY	183	252	173	266	192
GUTHRIE	144	101	242	106	56
HAMILTON	134	202	132	209	140
HANCOCK	135	254	298	263	188
HARDIN	153	228	204	231	164
HARRISON	97	112	315	35	126
HENRY	362	232	144	284	161
HOWARD	240	359	232	362	290
HUMBOLDT	74	209	302	209	132
IDA	36	147	344	113	154
IOWA	272	237	123	251	179
JACKSON	320	349	52	349	278
JASPER	221	186	160	159	123
JEFFERSON	332	206	161	258	137
JOHNSON	305	269	88	285	214
JONES	294	318	69	320	260
KEOKUK	299	217	154	207	145
KOSSUTH	111	226	315	204	165
LEE	409	213	153	307	206
LINN	263	299	93	286	236
LOUISA	373	257	106	265	181
LUCAS	259	116	240	170	60
LYON	82	270	452	189	280
MADISON	196	104	254	105	42
MAHASKA	272	183	185	182	115
MARION	247	151	196	156	95
MARSHALL	201	221	177	227	159
MILLS	134	51	360	35	69
MITCHELL	205	326	263	331	272

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	CHEROKEE	CLARINDA	CLINTON	C BLUFFS	CRESTON
MONONA	77	154	325	67	142
MONROE	287	149	205	202	88
MONTGOMERY	156	29	336	59	45
MUSCATINE	350	270	79	272	221
O BRIEN	30	203	406	140	218
OSCEOLA	57	237	417	162	246
PAGE	181	7	377	79	68
PALO ALTO	75	183	343	200	184
PLYMOUTH	38	215	402	132	235
POCAHONTAS	48	180	301	180	151
POLK	192	159	190	170	97
POTT MIE	110	74	353	22	88
POWESHIEK	257	217	154	222	156
RINGGOLD	238	46	314	128	35
SAC	49	127	211	122	142
SCOTT	376	336	38	300	255
SHELBY	98	83	291	61	99
SIOUX	61	247	402	163	272
STORY	178	190	183	190	127
TAMA	224	244	155	252	180
TAYLOR	208	24	342	107	39
UNION	208	72	301	110	10
VAN BUREN	361	177	183	259	161
WAPELLO	313	176	183	229	129
WARREN	217	134	224	131	71
WASHINGTON	331	227	127	234	176
WAYNE	280	97	252	173	81
WEBSTER	101	191	264	183	124
WINNEBAGO	137	274	316	272	211
WINNESHIEK	247	380	200	377	316
WOODBURY	55	181	386	103	209
WORTH	173	309	281	299	241
WRIGHT	100	235	267	231	172

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	D PORT	DECORAH	D MOINES	DUBUQUE	ES VILLE
ADAIR	255	303	70	297	163
ADAMS	277	344	110	351	186
ALLAMAKEE	182	18	248	103	179
APPANOOSE	185	264	108	259	311
AUDUBON	246	303	81	315	156
BENTON	127	109	120	108	251
BLACK HAWK	173	93	115	92	201
BOONE	224	217	51	217	147
BREMER	192	70	165	109	181
BUCHANAN	145	73	163	67	217
BUENA VISTA	351	225	172	251	70
BUTLER	220	97	135	138	161
CALHOUN	304	220	116	221	89
CARROLL	284	258	104	173	119
CASS	246	324	94	328	158
CEDAR	49	156	165	78	320
CERRO GORDO	270	96	133	194	115
CHEROKEE	376	253	200	277	94
CHICKASAW	216	36	183	128	158
CLARKE	213	283	52	284	247
CLAY	384	187	199	291	42
CLAYTON	144	56	225	68	227
CLINTON	23	183	205	53	367
CRAWFORD	314	303	129	306	129
DALLAS	196	249	28	254	176
DAVIS	164	231	134	237	336
DECATUR	241	307	78	311	274
DELAWARE	116	86	202	36	265
DES MOINES	72	212	191	144	392
DICKINSON	396	184	216	297	19
DUBUQUE	83	116	211	15	294
EMMET	370	161	192	299	0
FAYETTE	167	35	201	86	200

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	D PORT	DECORAH	D MOINES	DUBUQUE	ES VILLE
FLOYD	241	74	170	160	138
FRANKLIN	240	124	103	167	135
FREMONT	342	413	180	401	244
GREENE	251	239	72	244	125
GRUNDY	189	125	85	137	187
GUTHRIE	222	276	56	287	133
HAMILTON	244	175	71	171	137
HANCOCK	291	124	105	224	86
HARDIN	210	152	79	203	166
HARRISON	293	351	120	339	190
HENRY	99	178	164	164	361
HOWARD	241	31	210	153	132
HUMBOLDT	307	181	120	229	83
IDA	327	277	160	268	112
IOWA	85	145	102	139	278
JACKSON	51	148	200	24	320
JASPER	140	193	41	199	231
JEFFERSON	119	177	145	187	345
JOHNSON	56	145	118	111	317
JONES	72	126	173	54	316
KEOKUK	105	176	97	173	306
KOSSUTH	326	134	146	260	49
LEE	112	239	209	171	409
LINN	99	111	154	87	283
LOUISA	62	192	166	135	375
LUCAS	184	268	63	187	259
LYON	470	242	278	361	85
MADISON	226	276	42	284	213
MAHASKA	136	206	64	144	285
MARION	166	232	39	171	254
MARSHALL	174	133	46	165	209
MILLS	332	392	153	383	220
MITCHELL	265	64	185	184	112

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	D PORT	DECORAH	D MOINES	DUBUQUE	ES VILLE
MONONA	356	323	155	345	169
MONROE	169	235	69	232	294
MONTGOMERY	306	363	133	356	183
MUSCATINE	35	205	170	98	363
O BRIEN	391	246	221	322	67
OSCEOLA	432	212	210	327	51
PAGE	309	385	154	393	207
PALO ALTO	354	185	176	262	31
PLYMOUTH	269	290	232	311	127
POCAHONTAS	317	213	142	223	60
POLK	170	220	14	222	199
POTT MIE	281	363	126	309	190
POWESHIEK	130	167	72	167	256
RINGGOLD	278	331	104	332	243
SAC	307	255	142	250	92
SCOTT	7	199	173	68	373
SHELBY	267	183	93	345	160
SIOUX	429	243	255	358	99
STORY	191	189	44	185	185
TAMA	153	133	78	142	228
TAYLOR	277	356	123	359	204
UNION	241	310	74	311	214
VAN BUREN	138	198	160	210	368
WAPELLO	141	206	113	211	321
WARREN	197	243	24	251	220
WASHINGTON	75	149	130	146	332
WAYNE	214	145	87	283	282
WEBSTER	273	202	94	197	112
WINNEBAGO	320	109	135	236	58
WINNESHIEK	208	0	235	121	168
WOODBURY	366	190	191	302	145
WORTH	287	94	158	214	85
WRIGHT	272	149	86	199	111

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	FAIRFIELD	F DODGE	F MADISON	GRINNELL	INDEPEND
ADAIR	166	108	240	133	232
ADAMS	182	140	229	173	270
ALLAMAKEE	203	208	202	186	83
APPANOOSE	72	208	103	90	185
AUDUBON	226	104	281	123	233
BENTON	96	159	154	62	41
BLACK HAWK	136	106	199	78	25
BOONE	193	49	251	92	153
BREMER	160	124	224	105	49
BUCHANAN	114	128	167	103	0
BUENA VISTA	307	68	382	214	214
BUTLER	182	92	250	76	69
CALHOUN	261	27	327	160	153
CARROLL	249	70	178	141	197
CASS	198	128	276	147	264
CEDAR	106	231	102	103	96
CERRO GORDO	224	94	296	136	122
CHEROKEE	337	96	402	247	243
CHICKASAW	185	147	250	120	70
CLARKE	103	150	167	114	216
CLAY	337	97	403	240	217
CLAYTON	173	184	173	163	59
CLINTON	144	244	139	124	123
CRAWFORD	265	102	323	174	228
DALLAS	164	72	239	85	183
DAVIS	45	238	66	107	156
DECATUR	120	160	140	131	240
DELAWARE	153	151	142	128	30
DES MOINES	52	292	31	146	159
DICKINSON	356	118	423	258	247
DUBUQUE	171	181	162	156	54
EMMET	337	107	399	238	235
FAYETTE	142	155	199	134	34

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	FAIRFIELD	F DODGE	F MADISON	GRINNELL	INDEPEND
FLOYD	210	119	261	102	94
FRANKLIN	208	69	268	105	100
FREMONT	212	216	248	250	344
GREENE	214	45	279	109	166
GRUNDY	146	90	213	47	58
GUTHRIE	196	85	255	114	204
HAMILTON	206	33	272	106	104
HANCOCK	260	72	328	161	153
HARDIN	173	60	244	75	88
HARRISON	257	158	342	173	292
HENRY	23	268	40	125	136
HOWARD	212	168	250	148	92
HUMBOLDT	262	21	327	162	153
IDA	305	83	369	206	202
IOWA	60	183	123	43	71
JACKSON	165	229	159	154	91
JASPER	114	124	182	18	123
JEFFERSON	0	240	65	100	113
JOHNSON	73	204	95	76	79
JONES	133	203	132	117	71
KEOKUK	40	201	103	61	102
KOSSUTH	294	54	359	194	181
LEE	59	304	5	165	168
LINN	105	171	125	85	46
LOUISA	59	269	50	131	137
LUCAS	76	159	137	89	187
LYON	418	175	486	311	317
MADISON	138	104	209	101	209
MAHASKA	61	179	123	41	127
MARION	88	148	157	53	158
MARSHALL	135	101	200	37	100
MILLS	207	191	284	220	322
MITCHELL	218	144	290	126	121

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	FAIRFIELD	F DODGE	F MADISON	GRINNELL	INDEPEND
MONONA	308	138	365	212	268
MONROE	47	187	114	64	172
MONTGOMERY	182	173	258	191	295
MUSCATINE	82	265	72	111	126
O BRIEN	366	126	433	261	246
OSCEOLA	385	148	452	289	281
PAGE	212	188	221	216	321
PALO ALTO	313	74	378	214	208
PLYMOUTH	376	136	440	272	283
POCAHONTAS	285	45	349	180	181
POLK	146	93	209	57	150
POTT MIE	237	168	287	188	286
POWESHIEK	85	153	152	14	96
RINGGOLD	154	138	169	165	268
SAC	285	63	350	185	183
SCOTT	124	273	119	121	137
SHELBY	228	128	308	146	260
SIOUX	391	151	455	298	282
STORY	162	77	230	63	119
TAMA	114	120	180	35	69
TAYLOR	181	159	193	183	290
UNION	128	114	196	137	242
VAN BUREN	21	259	43	120	133
WAPELLO	25	213	93	74	134
WARREN	120	119	179	75	178
WASHINGTON	40	225	74	89	101
WAYNE	92	183	116	113	212
WEBSTER	235	5	300	131	127
WINNEBAGO	285	91	343	176	168
WINNESHIEK	176	198	239	168	73
WOODBURY	350	107	414	251	234
WORTH	251	117	321	148	144
WRIGHT	234	42	297	132	122

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	INDIANOLA	IOWA CTY	I FALLS	KNOXVILLE	LE MARS
ADAIR	51	195	158	76	211
ADAMS	92	241	198	122	220
ALLAMAKEE	263	124	158	240	304
APPANOOSE	86	148	161	60	344
AUDUBON	103	191	157	123	162
BENTON	139	63	101	116	272
BLACK HAWK	158	108	52	135	249
BOONE	72	161	76	101	190
BREMER	176	133	70	154	214
BUCHANAN	178	85	89	158	279
BUENA VISTA	196	282	129	223	54
BUTLER	149	156	44	130	189
CALHOUN	139	236	87	165	115
CARROLL	127	220	122	156	130
CASS	101	226	186	104	183
CEDAR	163	31	180	151	374
CERRO GORDO	154	206	49	134	189
CHEROKEE	223	314	156	254	29
CHICKASAW	202	150	93	182	253
CLARKE	32	176	139	59	270
CLAY	217	314	145	249	76
CLAYTON	196	109	126	196	268
CLINTON	202	67	209	201	375
CRAWFORD	154	253	158	176	106
DALLAS	51	142	105	79	209
DAVIS	113	121	187	83	372
DECATUR	57	197	163	82	296
DELAWARE	208	74	108	189	271
DES MOINES	161	76	240	132	432
DICKINSON	243	328	168	273	101
DUBUQUE	231	93	130	210	339
EMMET	218	313	147	250	119
FAYETTE	214	107	109	190	243

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	INDIANOLA	IOWA CTY	I FALLS	KNOXVILLE	LE MARS
FLOYD	176	176	66	154	218
FRANKLIN	125	180	17	110	162
FREMONT	165	313	272	195	187
GREENE	96	188	100	124	158
GRUNDY	122	124	38	95	224
GUTHRIE	79	168	134	106	179
HAMILTON	93	176	35	115	161
HANCOCK	135	232	68	165	161
HARDIN	92	152	13	93	192
HARRISON	148	241	214	180	104
HENRY	137	53	217	118	403
HOWARD	218	176	117	209	307
HUMBOLDT	146	202	70	172	108
IDA	186	264	144	212	72
IOWA	113	30	130	89	315
JACKSON	224	90	170	209	359
JASPER	55	85	74	29	268
JEFFERSON	120	75	194	88	373
JOHNSON	133	3	160	118	349
JONES	192	59	146	176	334
KEOKUK	76	61	150	51	342
KOSSUTH	169	265	103	199	145
LEE	179	90	258	157	437
LINN	167	35	126	137	302
LOUISA	135	56	218	107	391
LUCAS	41	153	116	26	296
LYON	297	393	222	328	44
MADISON	26	166	138	51	232
MAHASKA	52	87	129	25	311
MARION	26	118	107	0	281
MARSHALL	64	113	54	60	246
MILLS	137	273	247	166	182
MITCHELL	205	205	90	183	222

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	INDIANOLA	IOWA CTY	I FALLS	KNOXVILLE	LE MARS
MONONA	185	291	180	218	70
MONROE	68	117	138	29	328
MONTGOMERY	122	247	223	139	188
MUSCATINE	142	44	206	136	392
O BRIEN	245	346	176	276	43
OSCEOLA	272	361	198	299	59
PAGE	141	281	247	159	217
PALO ALTO	190	284	122	221	109
PLYMOUTH	258	355	193	281	7
POCAHONTAS	167	266	92	196	82
POLK	29	116	73	41	228
POTT MIE	112	264	221	138	151
POWESHIEK	79	37	102	61	282
RINGGOLD	89	234	192	111	265
SAC	166	270	123	197	87
SCOTT	197	54	214	168	419
SHELBY	117	214	182	146	137
SIOUX	278	361	214	307	22
STORY	59	130	46	73	209
TAMA	110	87	72	89	267
TAYLOR	110	246	216	134	243
UNION	60	203	161	83	248
VAN BUREN	139	96	213	108	391
WAPELLO	90	97	160	63	344
WARREN	0	136	105	25	258
WASHINGTON	104	35	178	78	350
WAYNE	62	168	137	52	316
WEBSTER	113	206	59	147	146
WINNEBAGO	154	256	90	187	178
WINNESHIEK	243	147	141	232	284
WOODBURY	223	304	157	255	36
WORTH	178	228	74	157	214
WRIGHT	107	202	41	144	135

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	MAQUOKETA	M LLTOWN	MASON CTY	MT P ANT	MUSCATINE
ADAIR	283	148	216	193	193
ADAMS	314	186	257	182	244
ALLAMAKEE	139	173	109	176	166
APPANOOSE	228	102	214	89	160
AUDUBON	278	136	210	254	219
BENTON	79	53	144	115	107
BLACK HAWK	124	65	96	160	154
BOONE	184	59	130	216	217
BREMER	146	89	65	186	173
BUCHANAN	101	89	120	136	126
BUENA VISTA	299	176	147	336	324
BUTLER	167	63	54	210	200
CALHOUN	259	127	137	281	276
CARROLL	235	108	175	264	256
CASS	286	172	231	226	220
CEDAR	48	118	220	85	31
CERRO GORDO	224	94	10	257	251
CHEROKEE	327	206	160	367	355
CHICKASAW	169	108	56	193	199
CLARKE	247	107	192	126	182
CLAY	336	201	109	366	358
CLAYTON	100	152	120	146	131
CLINTON	20	155	246	121	59
CRAWFORD	263	137	209	295	286
DALLAS	221	76	156	194	197
DAVIS	200	133	218	65	126
DECATUR	277	152	217	147	208
DELAWARE	69	119	158	137	96
DES MOINES	117	182	277	25	44
DICKINSON	342	225	125	383	373
DUBUQUE	42	132	177	151	90
EMMET	335	201	107	361	356
FAYETTE	121	121	103	168	150

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	MAQUOKETA	M LLTOWN	MASON CTY	MT P ANT	MUSCATINE
FLOYD	191	205	29	226	224
FRANKLIN	196	72	32	235	227
FREMONT	383	253	327	235	309
GREENE	208	94	155	245	224
GRUNDY	139	32	82	175	169
GUTHRIE	253	119	183	227	196
HAMILTON	202	72	87	232	229
HANCOCK	255	126	28	287	278
HARDIN	169	44	60	203	197
HARRISON	336	191	261	286	268
HENRY	131	159	261	0	63
HOWARD	189	137	67	219	211
HUMBOLDT	239	128	87	287	281
IDA	312	168	191	335	332
IOWA	106	75	141	83	77
JACKSON	10	146	217	148	81
JASPER	158	35	111	137	133
JEFFERSON	154	130	228	23	82
JOHNSON	71	103	204	56	49
JONES	28	103	194	117	53
KEOKUK	141	94	192	65	75
KOSSUTH	277	161	64	320	314
LEE	149	200	299	33	81
LINN	53	83	172	95	76
LOUISA	95	160	265	37	26
LUCAS	232	105	190	97	153
LYON	414	284	191	448	443
MADISON	251	92	187	166	168
MAHASKA	172	68	167	85	104
MARION	191	65	139	118	117
MARSHALL	125	8	102	159	149
MILLS	373	235	300	230	301
MITCHELL	218	102	39	252	245

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	MAQUOKETA	M LLTOWN	MASON CTY	MT P ANT	MUSCATINE
MONONA	297	172	242	336	326
MONROE	197	92	190	70	132
MONTGOMERY	342	205	270	207	273
MUSCATINE	68	157	249	63	0
O BRIEN	367	231	134	394	389
OSCEOLA	374	249	156	411	404
PAGE	351	228	295	241	279
PALO ALTO	302	180	81	340	329
PLYMOUTH	366	249	199	404	396
POCAHONTAS	265	153	112	313	310
POLK	192	40	129	178	167
POTT MIE	324	203	270	264	254
POWESHIEK	141	48	150	110	100
RINGGOLD	311	179	251	178	242
SAC	176	147	168	316	310
SCOTT	34	156	263	106	44
SHELBY	306	160	232	254	241
SIOUX	366	254	165	418	402
STORY	156	30	101	192	183
TAMA	107	29	113	139	134
TAYLOR	318	199	259	206	246
UNION	277	151	219	151	210
VAN BUREN	172	156	254	41	103
WAPELLO	178	106	196	48	105
WARREN	222	72	160	137	142
WASHINGTON	114	121	220	38	43
WAYNE	249	119	213	118	153
WEBSTER	229	97	108	261	247
WINNEBAGO	272	144	48	305	301
WINNESHIEK	154	157	90	178	191
WOODBURY	304	207	218	356	339
WORTH	239	118	20	281	272
WRIGHT	228	99	61	256	249

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	NEWTON	PELLA	PERRY	OELWEIN	OSKALOOSA
ADAIR	109	101	59	251	103
ADAMS	152	140	102	290	141
ALLAMAKEE	209	224	258	51	211
APPANOOSE	87	60	155	204	58
AUDUBON	106	133	60	254	153
BENTON	83	99	133	53	93
BLACK HAWK	100	114	153	37	108
BOONE	78	106	23	159	127
BREMER	124	142	173	32	134
BUCHANAN	123	138	176	16	135
BUENA VISTA	195	230	127	183	254
BUTLER	95	104	144	56	112
CALHOUN	142	173	71	177	199
CARROLL	123	154	58	220	189
CASS	127	114	85	272	130
CEDAR	108	135	168	111	119
CERRO GORDO	123	149	145	104	193
CHEROKEE	227	251	156	208	277
CHICKASAW	145	153	193	54	154
CLARKE	92	76	83	232	86
CLAY	221	251	152	211	276
CLAYTON	183	182	236	45	193
CLINTON	142	160	201	141	161
CRAWFORD	153	188	81	255	208
DALLAS	55	66	17	194	92
DAVIS	104	79	180	176	56
DECATUR	115	99	100	249	102
DELAWARE	156	172	209	45	166
DES MOINES	165	135	231	178	112
DICKINSON	242	275	178	240	297
DUBUQUE	180	193	235	66	183
EMMET	219	249	159	211	279
FAYETTE	159	173	205	19	164

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	NEWTON	PELLA	PERRY	OELWEIN	OSKALOOSA
FLOYD	134	126	166	78	136
FRANKLIN	94	120	115	87	150
FREMONT	227	210	173	363	205
GREENE	100	127	28	188	154
GRUNDY	69	86	116	72	95
GUTHRIE	81	93	34	225	141
HAMILTON	90	120	66	120	148
HANCOCK	146	177	115	136	195
HARDIN	61	96	87	100	113
HARRISON	154	190	110	297	210
HENRY	139	108	205	154	86
HOWARD	173	178	218	73	185
HUMBOLDT	149	172	81	129	201
IDA	186	219	116	233	245
IOWA	55	65	133	89	62
JACKSON	178	191	227	107	178
JASPER	0	29	70	137	45
JEFFERSON	114	85	189	130	60
JOHNSON	84	100	144	100	93
JONES	146	158	199	87	152
KEOKUK	75	47	147	122	25
KOSSUTH	180	212	104	170	234
LEE	180	150	251	187	117
LINN	109	119	163	65	114
LOUISA	144	114	222	190	95
LUCAS	69	52	108	205	59
LYON	304	332	231	280	356
MADISON	83	72	45	221	77
MAHASKA	45	17	112	145	0
MARION	30	13	97	168	25
MARSHALL	28	53	71	113	74
MILLS	196	178	148	332	195
MITCHELL	148	151	189	103	159

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	NEWTON	PELLA	PERRY	OELWEIN	OSKALOOSA
MONONA	193	228	122	269	252
MONROE	63	35	135	174	29
MONTGOMERY	169	153	124	316	169
MUSCATINE	133	105	173	148	104
O BRIEN	251	280	179	241	304
OSCEOLA	272	300	203	247	324
PAGE	194	176	143	334	174
PALO ALTO	200	230	131	181	252
PLYMOUTH	251	291	187	241	316
POCAHONTAS	169	200	96	153	223
POLK	35	51	40	166	69
POTT MIE	167	148	122	311	165
POWESHIEK	29	42	102	106	36
RINGGOLD	144	130	101	283	139
SAC	164	198	100	181	224
SCOTT	139	154	199	155	138
SHELBY	128	158	80	265	176
SIOUX	279	314	209	276	340
STORY	48	64	51	134	82
TAMA	55	70	101	83	70
TAYLOR	165	153	114	303	158
UNION	117	100	72	255	104
VAN BUREN	131	106	102	149	82
WAPELLO	86	59	161	152	34
WARREN	55	42	68	193	51
WASHINGTON	103	79	163	120	52
WAYNE	86	70	128	232	79
WEBSTER	118	148	52	148	172
WINNEBAGO	170	201	137	156	220
WINNESHIEK	194	203	242	56	205
WOODBURY	228	249	153	154	272
WORTH	148	175	161	124	188
WRIGHT	112	142	92	100	172

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	OTTUMWA	RED OAK	S DOAH	SIOUX CTY	SPENCER
ADAIR	137	67	94	203	188
ADAMS	133	28	56	213	195
ALLAMAKEE	231	380	407	324	202
APPANOOSE	49	148	142	331	313
AUDUBON	192	68	95	151	134
BENTON	96	246	288	284	242
BLACK HAWK	114	276	309	230	211
BOONE	163	147	178	185	156
BREMER	137	293	325	265	207
BUCHANAN	134	294	332	253	240
BUENA VISTA	289	133	153	96	32
BUTLER	156	266	300	239	158
CALHOUN	232	142	169	100	86
CARROLL	219	106	133	120	97
CASS	168	42	68	170	139
CEDAR	130	271	324	349	342
CERRO GORDO	211	260	291	197	106
CHEROKEE	318	156	177	60	58
CHICKASAW	157	320	348	257	157
CLARKE	77	83	109	263	195
CLAY	321	158	178	112	6
CLAYTON	197	357	392	328	244
CLINTON	167	316	368	387	354
CRAWFORD	235	88	96	71	101
DALLAS	145	121	148	202	175
DAVIS	21	188	170	362	340
DECATUR	101	100	93	287	138
DELAWARE	175	337	362	284	253
DES MOINES	81	231	241	411	393
DICKINSON	331	181	200	137	17
DUBUQUE	193	341	385	307	278
EMMET	305	215	240	166	37
FAYETTE	167	338	362	300	217

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	OTTUMWA	RED OAK	S DOAH	SIOUX CTY	SPENCER
FLOYD	182	293	321	241	131
FRANKLIN	181	244	275	206	140
FREMONT	215	45	16	183	210
GREENE	184	123	153	156	131
GRUNDY	123	202	272	205	197
GUTHRIE	164	92	121	172	154
HAMILTON	183	192	220	152	135
HANCOCK	226	249	277	201	79
HARDIN	146	216	244	206	164
HARRISON	229	79	92	101	154
HENRY	48	209	219	383	368
HOWARD	181	345	372	305	182
HUMBOLDT	238	187	214	144	79
IDA	275	120	122	63	81
IOWA	69	240	258	323	280
JACKSON	187	349	369	324	332
JASPER	86	173	206	256	228
JEFFERSON	25	187	227	378	342
JOHNSON	100	248	292	324	313
JONES	158	318	337	346	306
KEOKUK	36	202	217	326	303
KOSSUTH	232	227	254	172	59
LEE	86	262	234	441	407
LINN	123	282	301	315	273
LOUISA	81	230	280	399	376
LUCAS	51	109	140	284	264
LYON	358	242	237	68	76
MADISON	108	94	120	223	195
MAHASKA	25	171	188	297	280
MARION	63	144	174	283	254
MARSHALL	106	209	242	232	210
MILLS	181	20	29	161	195
MITCHELL	211	320	348	272	149

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	OTTUMWA	RE'' OAK	S DOAH	SIOUX CTY	SPENCER
MONONA	276	120	131	45	133
MONROE	22	138	171	318	294
MONTGOMERY	157	3	30	182	164
MUSCATINE	105	275	292	404	259
O BRIEN	338	185	178	70	31
OSCEOLA	358	212	199	86	46
PAGE	183	24	14	209	185
PALO ALTO	289	190	182	149	30
PLYMOUTH	344	185	201	20	94
POCAHONTAS	250	155	181	114	55
POLK	120	146	178	90	196
POTT MIE	206	42	51	142	165
POWESHIEK	60	205	226	290	256
RINGGOLD	125	78	75	262	249
SAC	255	106	144	83	58
SCOTT	146	307	327	390	360
SHELBY	199	57	68	127	116
SIOUX	373	215	213	47	66
STORY	135	178	65	198	180
TAMA	94	234	257	253	224
TAYLOR	151	52	41	235	217
UNION	102	54	90	240	219
VAN BUREN	46	218	196	257	363
WAPELLO	0	161	199	347	316
WARREN	90	124	145	251	223
WASHINGTON	63	234	247	358	334
WAYNE	72	129	118	311	288
WEBSTER	207	168	198	125	107
WINNEBAGO	252	254	279	220	89
WINNESHIEK	206	368	397	306	185
WOODBURY	318	151	169	26	107
WORTH	214	288	317	242	122
WRIGHT	208	213	243	175	106

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	S LAKE	WASH TON	WATERLOO	WAVERLY	WEB CTY
ADAIR	144	157	213	221	123
ADAMS	151	203	254	261	160
ALLAMAKEE	247	152	106	96	185
APPANOOSE	170	109	162	181	185
AUDUBON	88	214	203	217	121
BENTON	229	82	45	69	131
BLACK HAWK	162	126	0	19	82
BOONE	112	179	124	134	41
BREMER	163	158	21	11	109
BUCHANAN	215	104	25	51	109
BUENA VISTA	7	309	184	151	100
BUTLER	135	173	44	17	79
CALHOUN	49	254	128	142	52
CARROLL	62	241	168	183	89
CASS	119	183	235	247	151
CEDAR	305	68	121	148	204
CERRO GORDO	145	221	96	70	75
CHEROKEE	26	342	213	177	122
CHICKASAW	190	163	44	35	128
CLARKE	204	139	196	205	112
CLAY	33	335	209	176	117
CLAYTON	215	144	83	72	162
CLINTON	312	104	154	176	245
CRAWFORD	58	276	202	219	118
DALLAS	138	158	156	168	71
DAVIS	303	82	136	153	238
DECATUR	231	160	214	232	133
DELAWARE	217	108	55	83	138
DES MOINES	358	56	186	212	268
DICKINSON	55	351	218	200	141
DUBUQUE	238	124	78	102	162
EMMET	78	328	202	170	127
FAYETTE	190	119	56	44	149

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	S LAKE	WASH TON	WATERLOO	WAVERLY	WEB CTY
FLOYD	159	191	68	44	101
FRANKLIN	126	200	69	44	52
FREMONT	171	266	327	331	238
GREENE	93	208	155	164	66
GRUNDY	160	145	33	45	67
GUTHRIE	113	188	189	199	97
HAMILTON	96	201	89	86	7
HANCOCK	115	254	120	94	57
HARDIN	127	169	60	71	38
HARRISON	93	271	261	263	175
HENRY	331	33	161	186	244
HOWARD	220	189	66	58	152
HUMBOLDT	64	396	124	96	45
IDA	36	292	176	167	105
IOWA	244	51	74	106	157
JACKSON	297	125	110	138	206
JASPER	194	105	100	109	103
JEFFERSON	305	38	136	158	217
JOHNSON	278	37	106	127	191
JONES	270	97	96	122	180
KEOKUK	269	34	103	125	179
KOSSUTH	97	286	160	132	76
LEE	378	67	197	223	282
LINN	240	66	75	99	148
LOUISA	344	37	164	189	243
LUCAS	232	109	173	181	133
LYON	108	404	286	244	202
MADISON	155	132	185	196	101
MAHASKA	249	62	108	111	156
MARION	217	88	127	178	122
MARSHALL	174	130	76	86	80
MILLS	148	257	295	310	211
MITCHELL	186	219	86	68	125

APPENDIX D (CONTINUED)

COUNTY	POTENTIAL PLANT LOCATION				
	S LAKE	WASH TON	WATERLOO	WAVERLY	WEB CTY
MONONA	75	287	241	261	146
MONROE	258	85	136	153	171
MONTGOMERY	126	232	276	283	184
MUSCATINE	323	47	156	180	238
O BRIEN	56	354	218	205	152
OSCEOLA	78	383	250	232	172
PAGE	147	235	296	304	209
PALO ALTO	65	307	177	146	96
PLYMOUTH	67	358	254	211	158
POCAHONTAS	34	275	153	123	65
POLK	162	145	127	137	67
POTT MIE	119	219	275	279	186
POWESHIEK	225	78	73	90	130
RINGGOLD	203	195	247	216	159
SAC	23	272	157	176	85
SCOTT	347	87	161	192	249
SHELBY	87	240	229	245	148
SIOUX	87	392	251	240	177
STORY	148	156	98	108	55
TAMA	196	108	45	58	96
TAYLOR	173	203	266	278	181
UNION	174	167	217	230	132
VAN BUREN	331	58	159	181	240
WAPELLO	283	56	113	132	214
WARREN	192	106	156	165	100
WASHINGTON	301	4	122	146	209
WAYNE	254	132	186	205	155
WEBSTER	74	262	102	112	23
WINNEBAGO	135	269	145	119	69
WINNESHIEK	228	154	93	80	175
WOODBURY	67	337	209	119	126
WORTH	165	242	117	92	102
WRIGHT	94	224	92	70	24